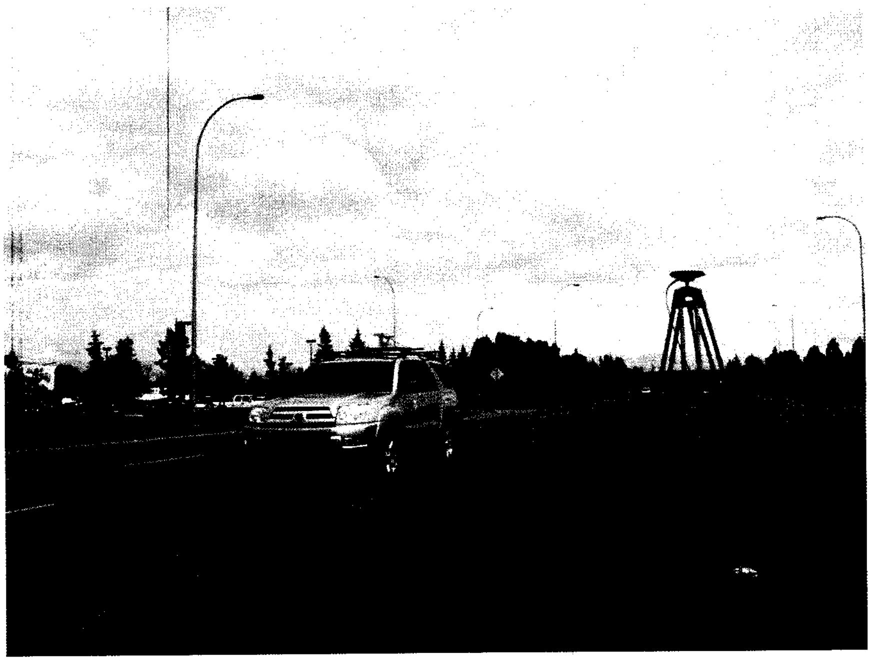
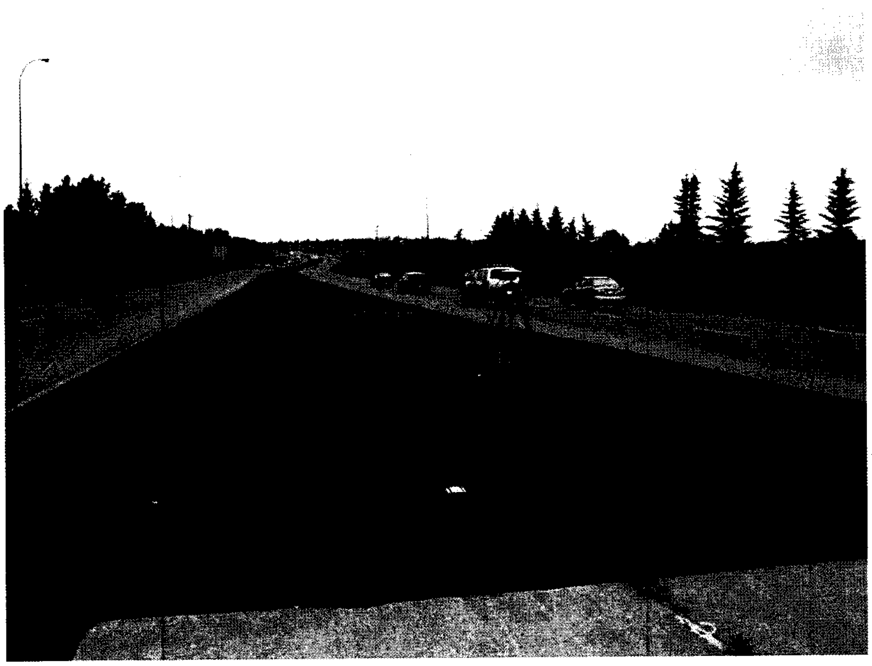


Major Rural Throughway Representative of Low Elevation Masking Trees - Also Shows Test Vehicle Passing GPS Infrastructure Station



Major Rural Throughway Representative of Typical Open Sky Conditions

Major Rural Throughway Experiencing Signal Shading On Left Side of the Road

13.1.4 Major Road (Urban and Rural)

Major Road Containing Foliage Signal Shading On the Vehicle's Right, and Less Substantial Foliage Signal Masking on Vehicle's Left

Major Road with Mostly Open Road Conditions and Parking Lot to the Right, with a 2 Story Building

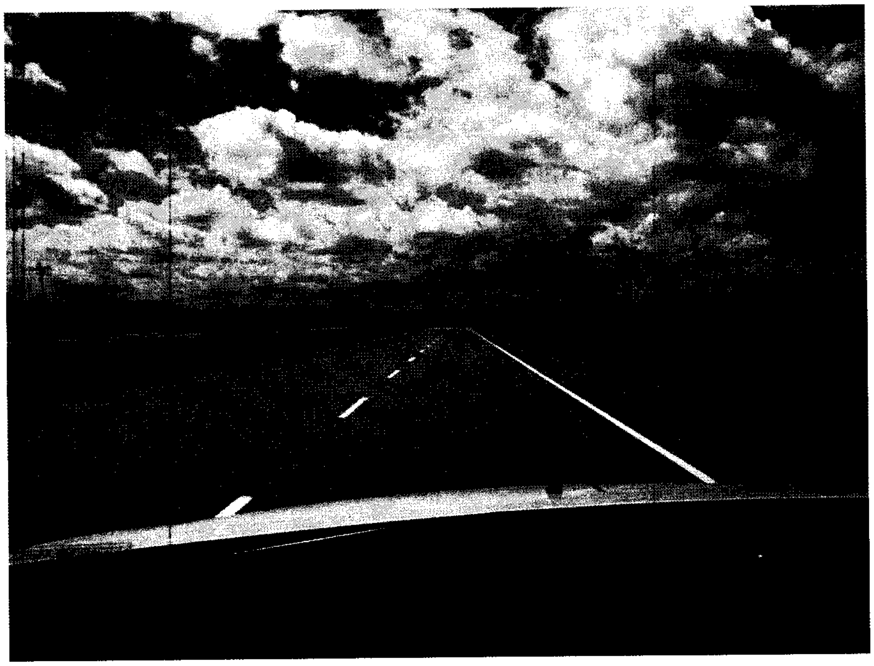
Major Rural Road Containing Only Sporadic Foliage Signal Masks

Major Road Containing Single Story Buildings Near V2I Station

13.1.5 Freeway/Interstate

Freeway with Open Sky Conditions

V2I Station Near a Freeway Exit with Excellent Open Sky Visibility



Freeway Road Selection Showing Open Sky Nature

Freeway Road Selection Showing Open Sky Nature

13.1.6 Mountain Roads

Mountain Road Selection Showing with Foliage Signal Masking 5-25 Degrees

Mountain Road Approaching Rocky Mountains, Which Includes Natural Signal Masking of 10-25 Degrees

13.1.7 Local Roads

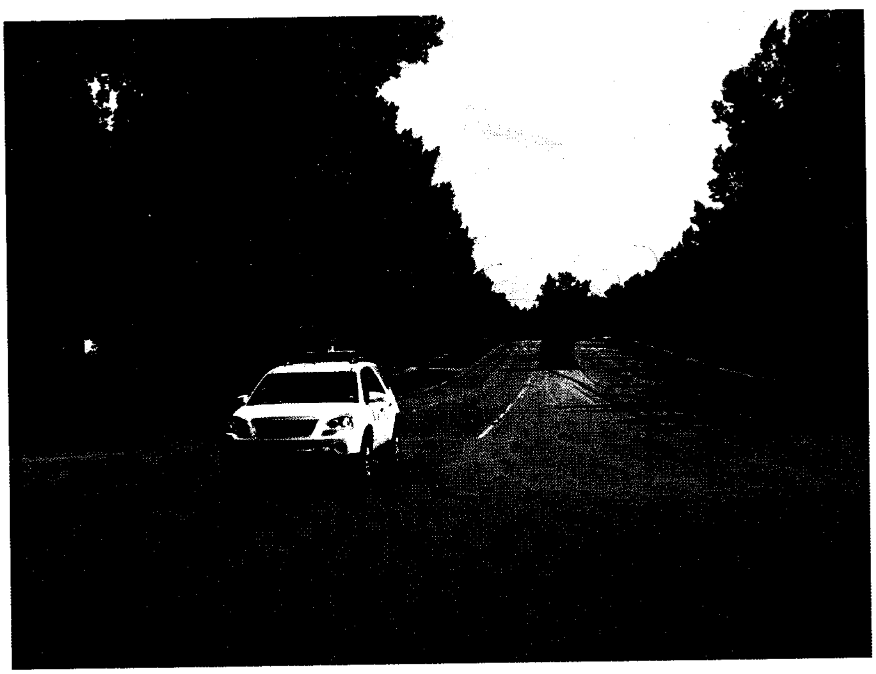
Local Residential Streets with 10-40 Degree Foliage Signal Masking

Local Residential Streets with Asymmetric Foliage Signal Masking

Local Residential Streets with High Signal Masking

Local Roads with Very High Foliage Signal Masking (> 60 Degrees) and Location of a V2I Station

Local Road Intersection Showing One Test Vehicle Approaching the Intersection and the Other Traveling Through the Intersection



Local Road Intersection with Near 90 Degree Foliage Signal Mask

13.2 Heading Accuracy

The heading accuracy relative to the Inertial Explorer heading is shown for the AW and B24W receivers. The heading has only been processed for a sample of the data that includes all environments except for the Deep Urban and Mountain Roads environments. All heading differences were removed if the speed of the vehicle was less than 5 miles per hour.

Figure 13-1 and Figure 13-2 show histograms of the heading errors for B24W and AW, respectively. The overall RMS heading error of the AW and B24W receivers is 1.4 and 1.6 degrees, respectively.

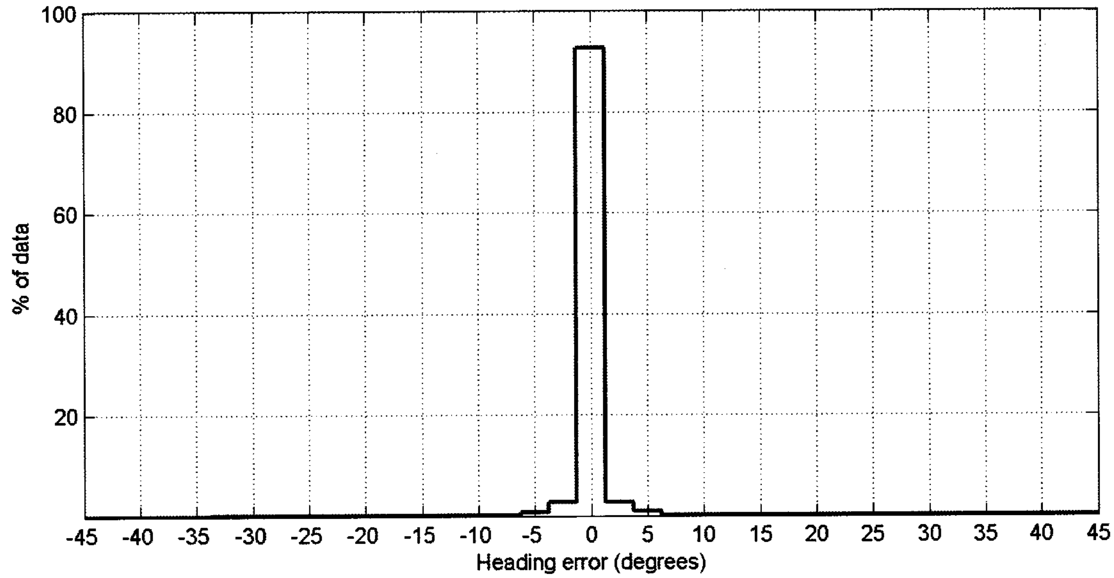


Figure 13-1: Histogram of the Heading Errors for B24W in All Environments

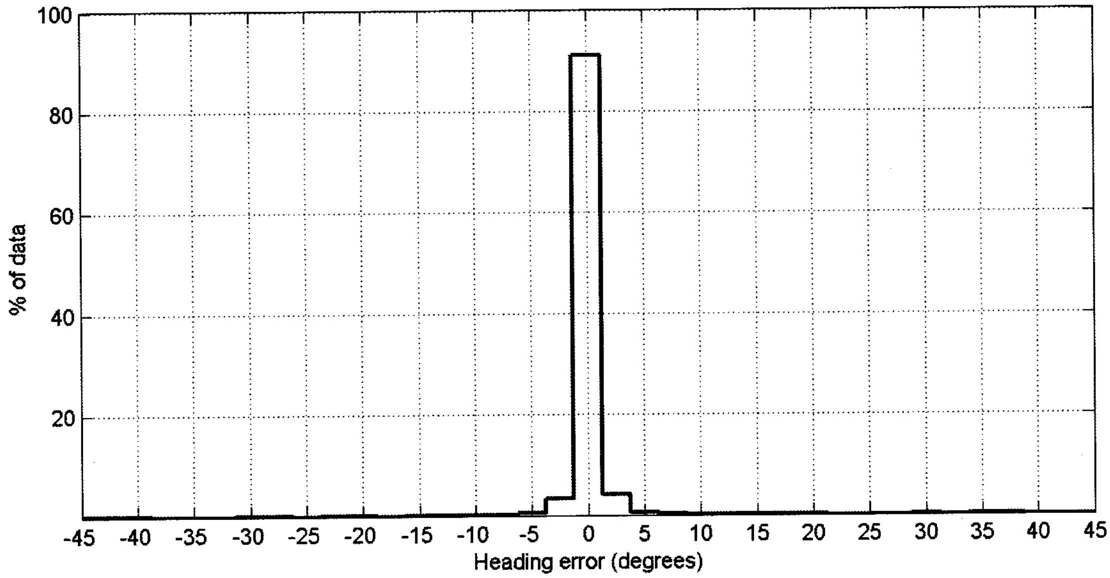


Figure 13-2: Histogram of the Heading Errors for AW in All Environments

13.3 Analysis of RTK Processing Packages

A select dataset is used to outline the difference in performance between various RTK SW packages. The RTK solutions show significant inconsistencies in combinations that in theory should provide the same level of accuracy (i.e., (BW-BN) and (BW-BW) (since WAAS is not used), (AW-BW) and (BW-AW)). Further investigation into these inconsistencies could not identify the reason for the differences. It may be due to nonlinear processes in the SW, including ambiguity resolution.

The PLANSoft SW is compared to the RTK results for the Mountain Road environment. This data segment was chosen because the RTK time-series plot is atypical.

Figure 13-3 shows the time series of the RTK and PLANSoft processing methods, and Figure 13-4 shows a histogram comparison for 04AUG09 Data Segment C for the (AW-AW) receiver combination. The RMS position errors for the RTK and PLANSoft positioning SW is 0.10 m (AT), 0.11 m (XT) and 0.02 m (AT), 0.03 m (XT), respectively. The PLANSoft solution performs consistently better than the RTK solution for this data segment.

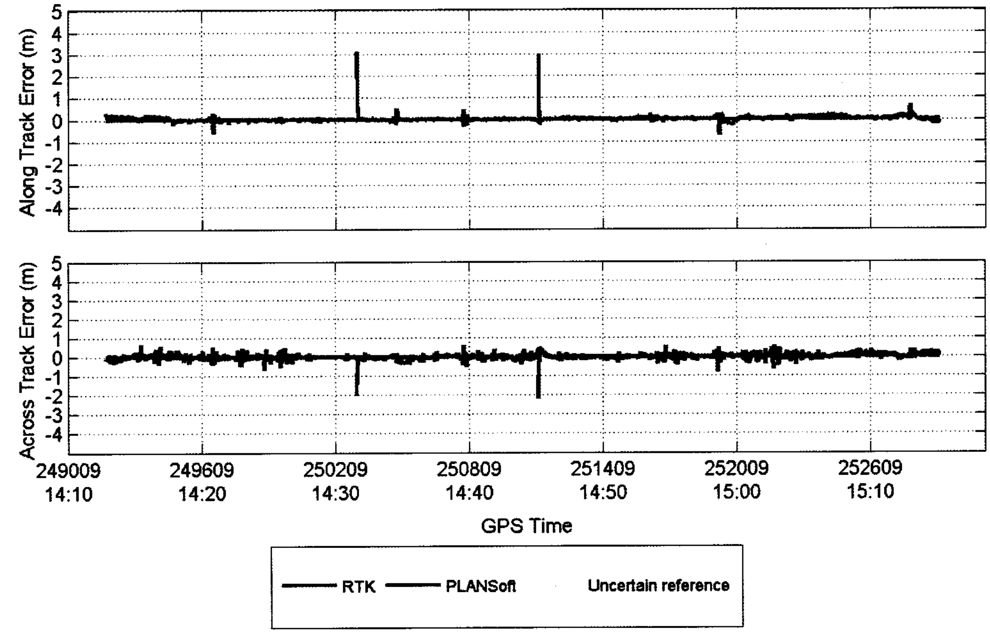


Figure 13-3: Time Series Comparing (AW-AW) for RTK and PLANSoft Processing Methods for 09AUG09 Mountain Road Environment

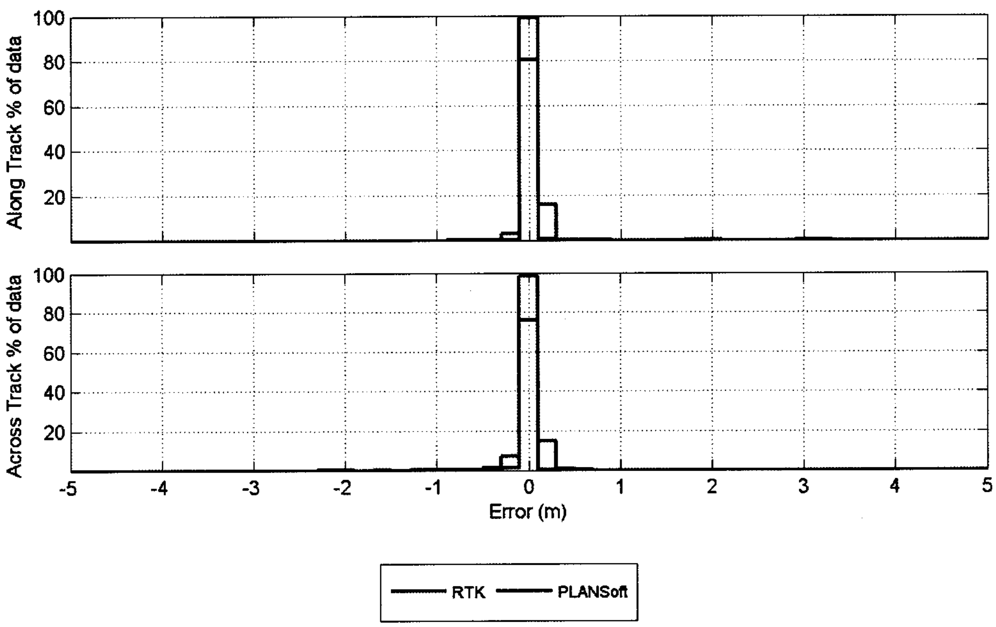


Figure 13-4: Histogram Comparing (AW-AW) for RTK and Plansoft Processing Methods for 09AUG09 Mountain Road Environment

Figure 13-5 shows the time series of the RTK and PLANSoft processing methods, and Figure 13-6 shows a histogram comparison for 04AUG09 Data Segment C for the (BW-BW) receiver combination. The RMS position errors for the RTK and PLANSoft positioning SW is 0.73(AT), 1.80(XT) and 0.62(AT), 0.56(XT), respectively. The RTK solution has biases in the along track direction that are not present in the PLANSoft processing SW. This suggests that the results may be slightly different if a different SW package is used or if the current SW package were tuned for the characteristics of the BW data.

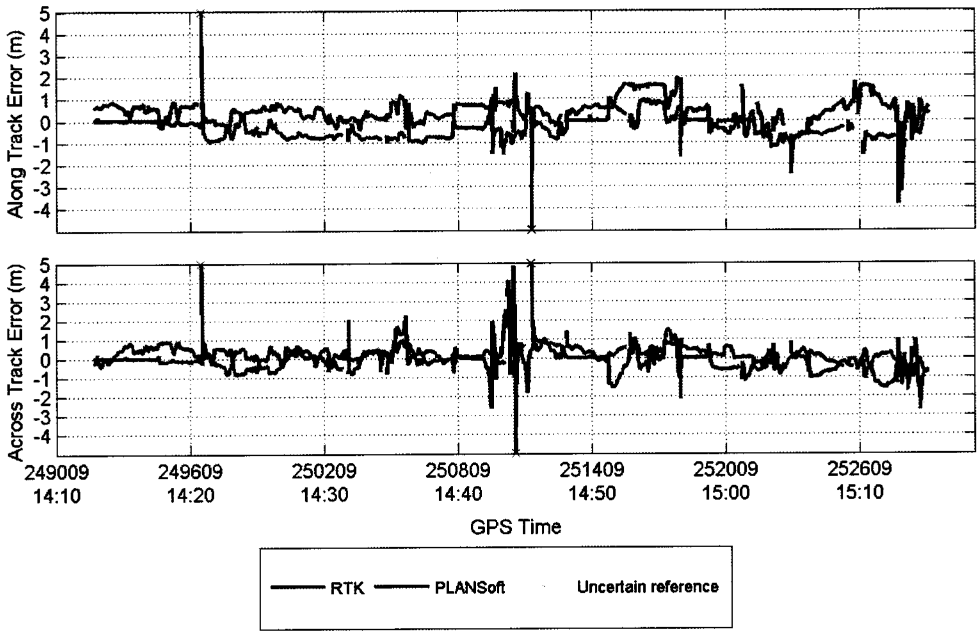


Figure 13-5: Time Series Comparing (BW-BW) For RTK and Plansoft Processing Methods for 09AUG09 Mountain Road Environment

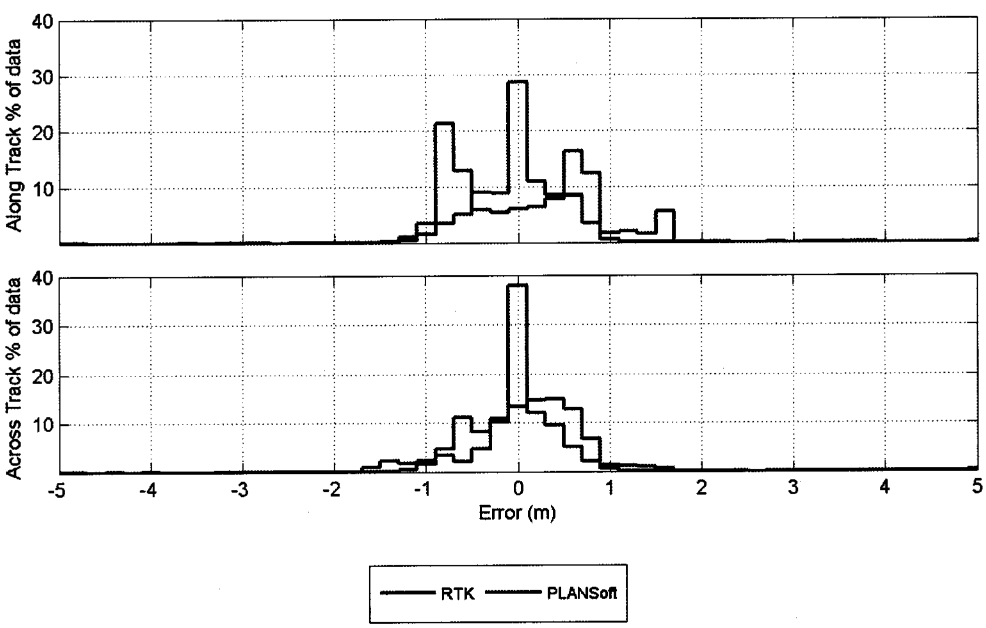


Figure 13-6: Histogram Comparing (BW-BW) For RTK and Plansoft Processing Methods for 09AUG09 Mountain Road Environment

VSC-A Final Report: Appendix I

Multiple-OBE Scalability Testing Results

List of Acronyms

CAMP	Crash Avoidance Metrics Partnership
HV	Host Vehicle
IPG	Inter-Packet Gap
ITS	Intelligent Transportation Systems
JPO	Joint Program Office
NHTSA	National Highway Traffic Safety Administration
OBE	On-Board Equipment
OTA	Over-the-Air
PER	Packet Error Rate
RITA	Research and Innovative Technology Administration
RSS	Receive Signal Strength
RTCM	Radio Technical Commission for Maritime Services
RTK	Real-Time Kinematic
RV	Remote Vehicle
USDOT	United States Department of Transportation
VSC2	Vehicle Safety Communications 2
VSC-A	Vehicle Safety Communications – Applications
V2V	Vehicle-to-Vehicle

Table of Contents

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1 Introduction

As noted in the main body of the Final Report under the data analysis of the multiple-On-Board Equipment (OBE) scalability testing, gathering the necessary data in order to analyze the Packet Error Rate (PER) and the Inter-Packet Gap (IPG) distribution was of primary interest. In addition to the results provided in the main body of the Final Report, this appendix will provide additional test results and analysis for the baseline and other tests, both static and moving, that were run as part of the preliminary scalability testing effort for the different channel configurations tested which are listed in Table 1 below.

Table 1: Channel Configurations for Scalability Testing

Configuration #	Channel Configuration Description
C1	IEEE 1609.4 channel switching mode
C2	Channel 172 dedicated safety channel (i.e., no channel switching)
C3	IEEE 1609.4 channel switching mode with messages submitted for transmission at a random time during each control channel interval
C4	IEEE 1609.4 channel switching mode with messages submitted for transmission via a time-shifting algorithm in an attempt to evenly space transmissions out during the intended channel

2 Baseline Scalability Test Results

In the main body of the Final Report, the Cumulative PER results and Average IPG results at a particular host vehicle (HV) for the baseline test configuration are presented. The results include the data for channel configurations C1 (1609.4–Timer Based), C3 (1609.4–Random Control Channel Interval Transmit), and C2 (Dedicated Safety Channel 172) for the 24, 48, and 60 radio scaling increment tests and show that the configuration method used for message transmission has a strong correlation to PER and IPG encountered. As expected, collisions at the beginning of a channel interval result in higher PER and correspondingly IPG for C1, which has the worst performance. Taking advantage of knowing when the channel interval begins and ends and implementing countermeasures in an attempt to avoid collisions as in C3 and C4 (1609.4–Time-shifted Control Channel Interval Transmit) provided better results than C1, which made no such attempt. C2, which provided full-time access to the channel, had the best PER and IPG performance and did not appear to be as affected as the other configurations as the scaling increments increased.

In addition to the PER and IPG test results discussed in the main body of the Final Report, other baseline test analysis looked at the PER versus Range, the PER versus Receive Signal Strength (RSS), and the IPG distribution for each of the channel configurations. For each of these tests, C2 outperformed C3 and C4, which in turn, outperformed C1 as in the previous test results. These test results are provided in the following sections.

2.1 PER vs. Range for Vehicle Pairs

Figure 1 below shows the test results for PER versus range for different HV / remote vehicle (RV) combinations. The results are shown for each of the channel configurations and radio scaling increments. For each HV / RV combination, the HV remains constant while a different RV is chosen at an increasing range (9m, 55m, 165m, and 260m) from the HV. Note that for each of the HV / RV combinations there is not a data point (indicated by a dot on the chart) for each and every scaling increment. This has to do with some of the RVs not participating in a particular scaling increment (e.g., green Prius for the 24 radio scaling increment) or due to the data not being collected for a particular scaling increment (e.g., 36 radio scaling increment for channel configurations C3 and C4).

For each scaling increment the results show that C1 has the highest PER while C2 has the lowest PER. C3 and C4 perform in between C1 and C2 and have similar results with one another.

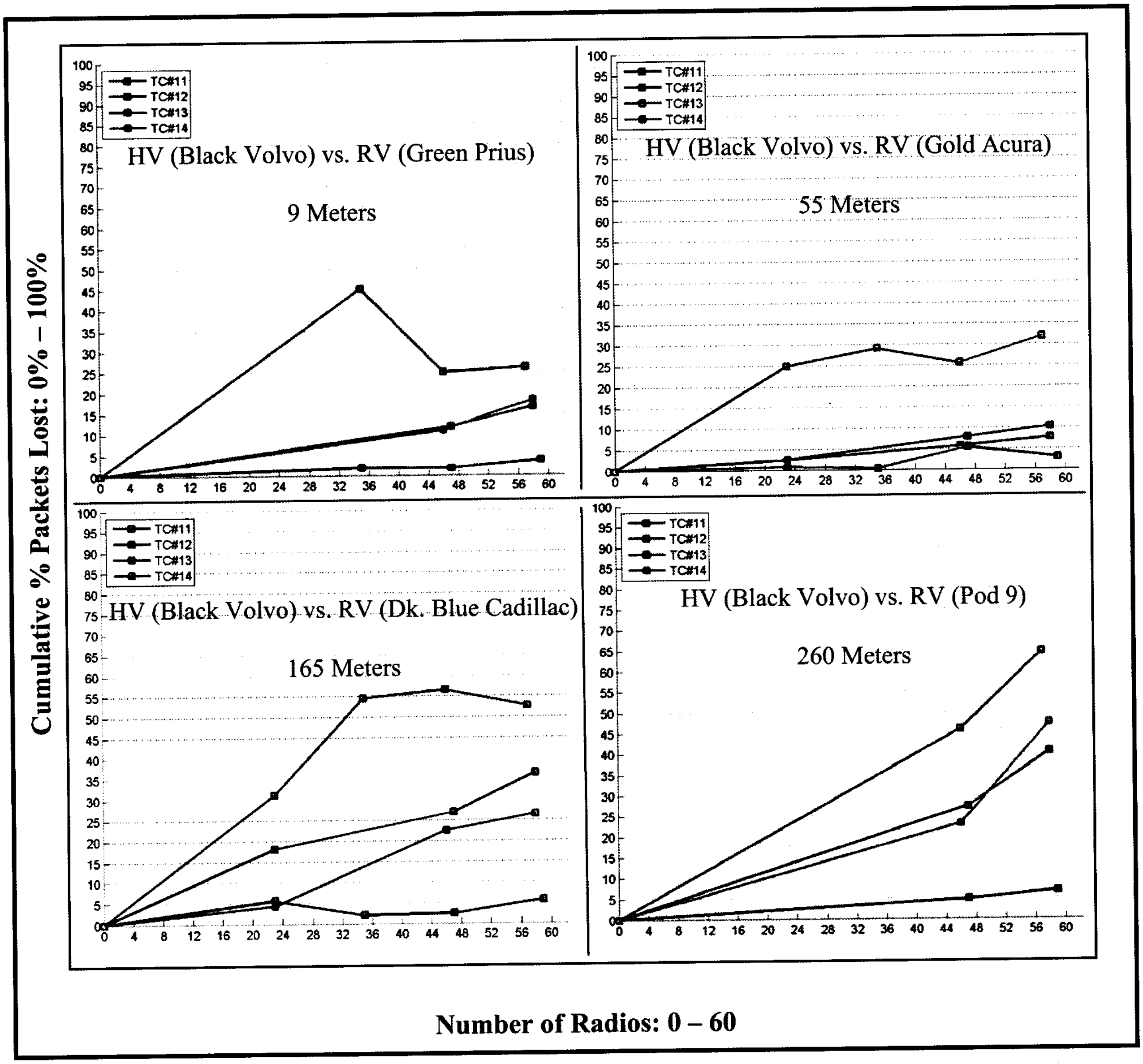


Figure 1: PER vs. Range for an HV / RV Combination – Ch. Cfg. 1, 2, 3, & 4 – 24, 48, 36, & 60 Tx Radios

2.2 PER vs. RSS and PER vs. Range for Multiple RVs

The PER versus RSS and the PER versus range for multiple RVs is presented as a scatter plot. Figure 2 provides an example of this type of plot for the 24 radio scaling increment along with some details on how to interpret the data contained in plot using the Pod 2 data as an example. Multiple HVs are shown on the same plot to evaluate overall test performance for the entire network.

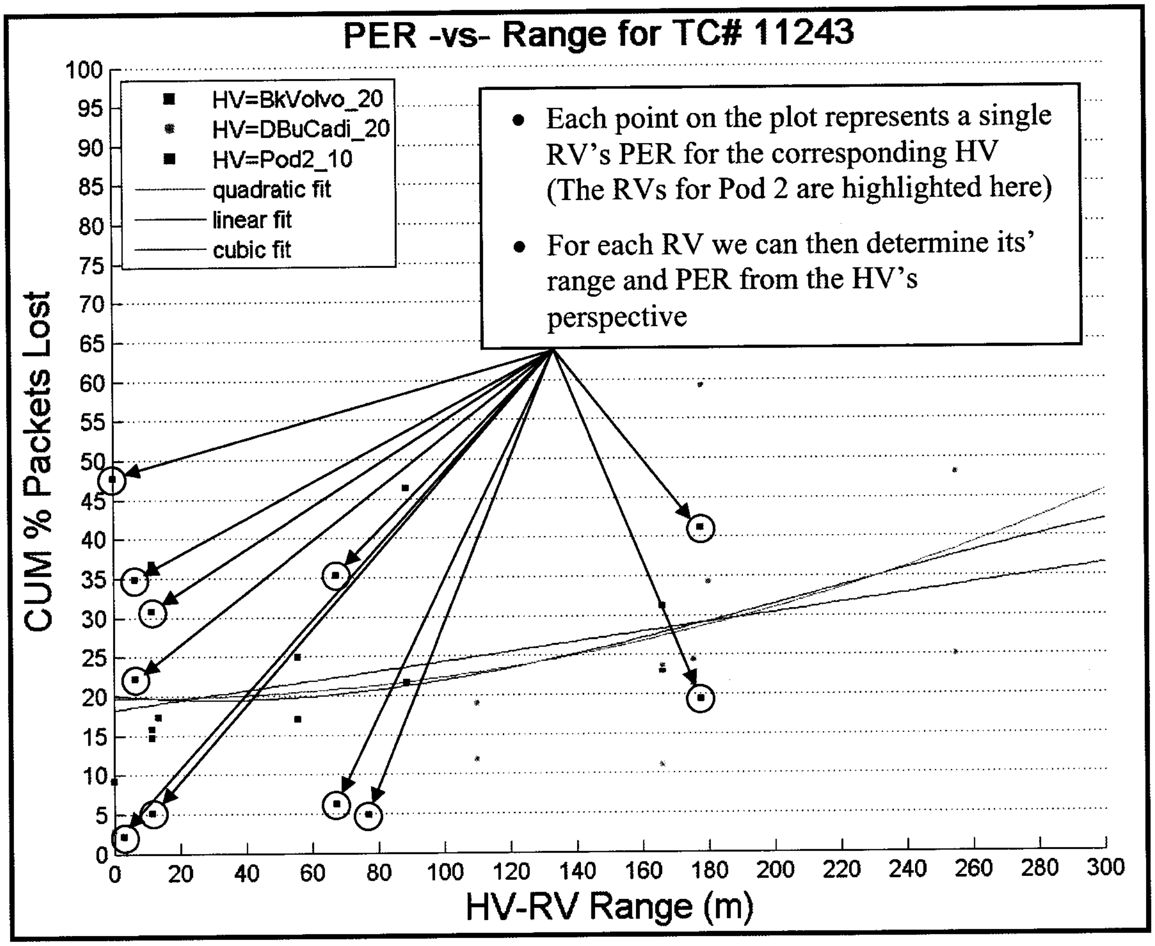


Figure 2: PER vs. Range for Multiple RVs – Example Plot for 24 Tx Radios

The left-side column of Figure 3 shows the PER versus HV / RV range for channel configurations C1, C3, and C2 for the 60 radio scaling increment. Note that these plots exclude the results of the second radio of each OBE due to it having a lower transmit power than the first radio of the OBE. Based on the large scattering of points, the channel configurations C1 and C3 charts indicate that PER is weakly correlated to range potentially due to varying signal strengths. Channel configuration C2, which minimizes packet collisions, appears to have a strong correlation between PER and range and allows better packet reception at greater ranges which was also shown to be the case in Section 2.1.

The right-side column of Figure 3 shows the PER versus average RSS for the same channel configurations and radio scaling increment as the HV / RV range charts. These charts indicate that PER is more strongly correlated to RSS for all channel configurations. Minimizing packet collisions allows better packet reception at weaker signal strengths, as shown with channel configuration C2 (dedicated safety channel).

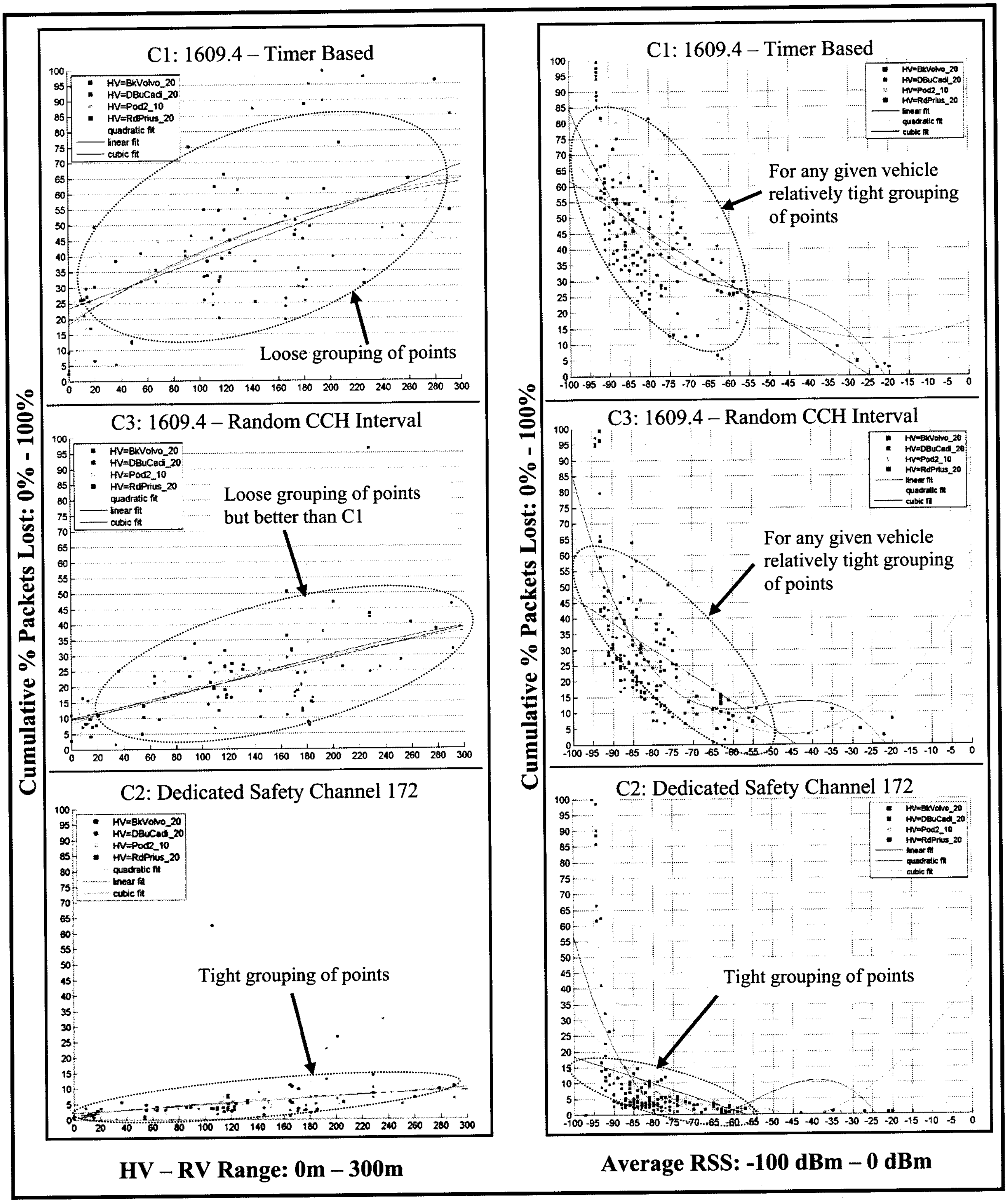


Figure 3: PER vs. Range & PER vs. Avg. RSS for Multiple RVs – Ch. Cfg. 1, 3, & 2 – 60 Tx Radios

2.3 IPG Distribution

Figure 4 shows the IPG distribution of all the packets received at V2 (black Volvo) which was part of the center cluster of radios. The IPG distribution shows that for channel configuration C1 some RVs were not heard from for periods of 400ms – 500ms while for channel configuration C2 the worst case was 200ms – 300ms. For future testing it would be useful to analyze the number of vehicles that fell within each of these bins due to the vehicles with the lower PER (and thus more received packets) potentially skewing these results.

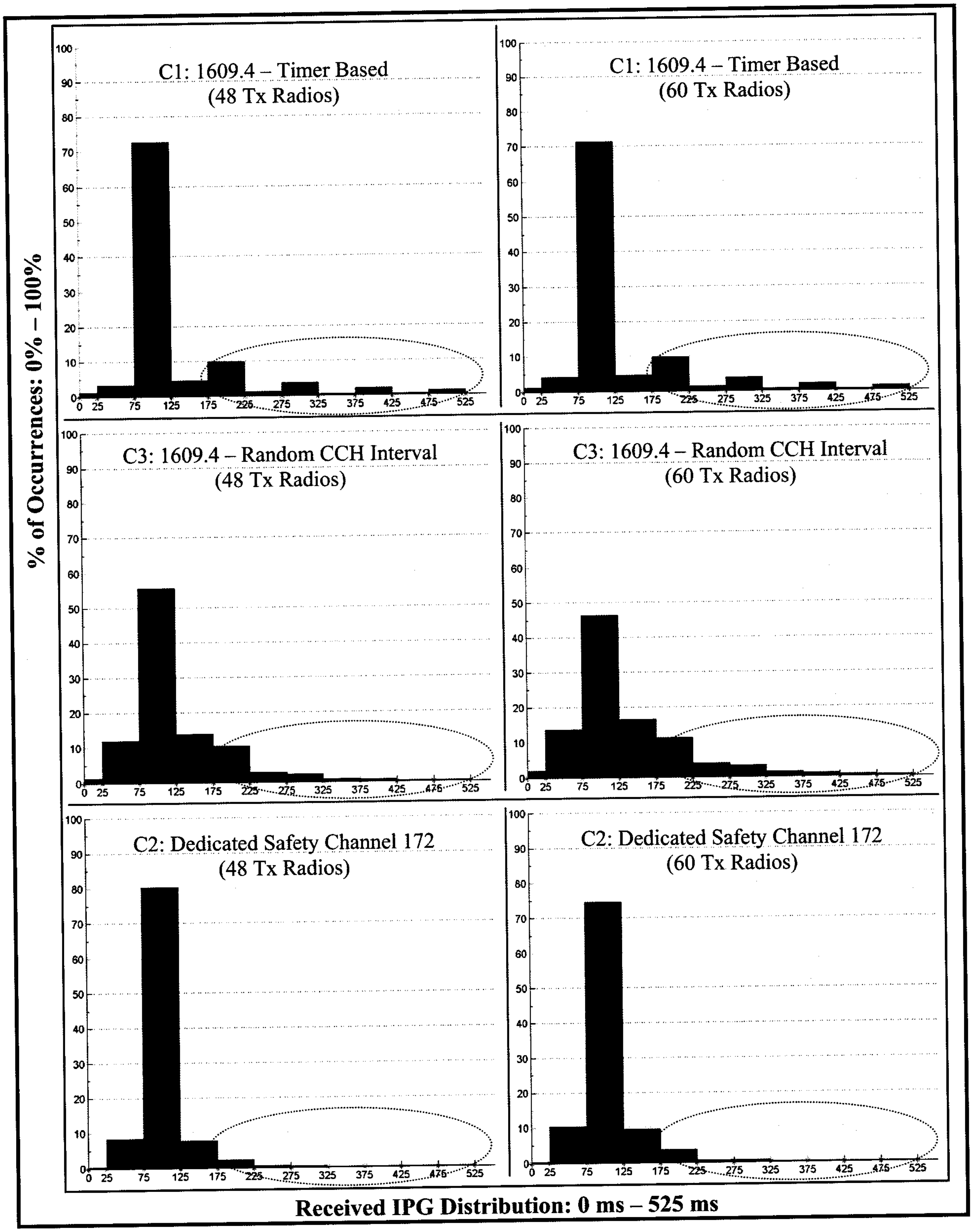


Figure 4: IPG Distribution – Ch. Cfg. 1, 3, & 2 – 48, & 60 Tx Radios

3 Non-Baseline Static Scalability Test Results

The baseline test results indicate that 1609.4 channel switching with no countermeasures to address the synchronized collision issue is not a viable channel configuration for V2V safety DSRC. Because of this, the non-baseline static tests focused on channel configurations C2 and C3 for the data gathering and analysis. The data analysis for these tests primarily looked at the PER and included PER versus message size, PER versus message transmit rate, and PER versus data transmit rate for the 48 and 60 radio scaling increments. These test results are provided in the following sections along with the baseline results for comparison. In addition, for the data transmit rate analysis the PER versus Range and PER versus RSS for baseline and non-baseline tests is provided. For all of these tests, due to the results being similar for both scaling increments, only the 60 radio scaling increment results are provided.

3.1 PER vs. Message Size

For this test, 86 bytes of padding were added to the Over-the-Air (OTA) message when compared to the baseline configuration for a total of 464 OTA bytes. These bytes represent (approximately) the Radio Technical Commission for Maritime Services (RTCM) 1002 data that would be present if Real-Time Kinematic (RTK) positioning was enabled and seven satellites were in view. The results show (Figure 5) that increasing the OTA packet length increased the PER for both channel configurations. This is caused from a higher OTA congestion level when using larger packet sizes.

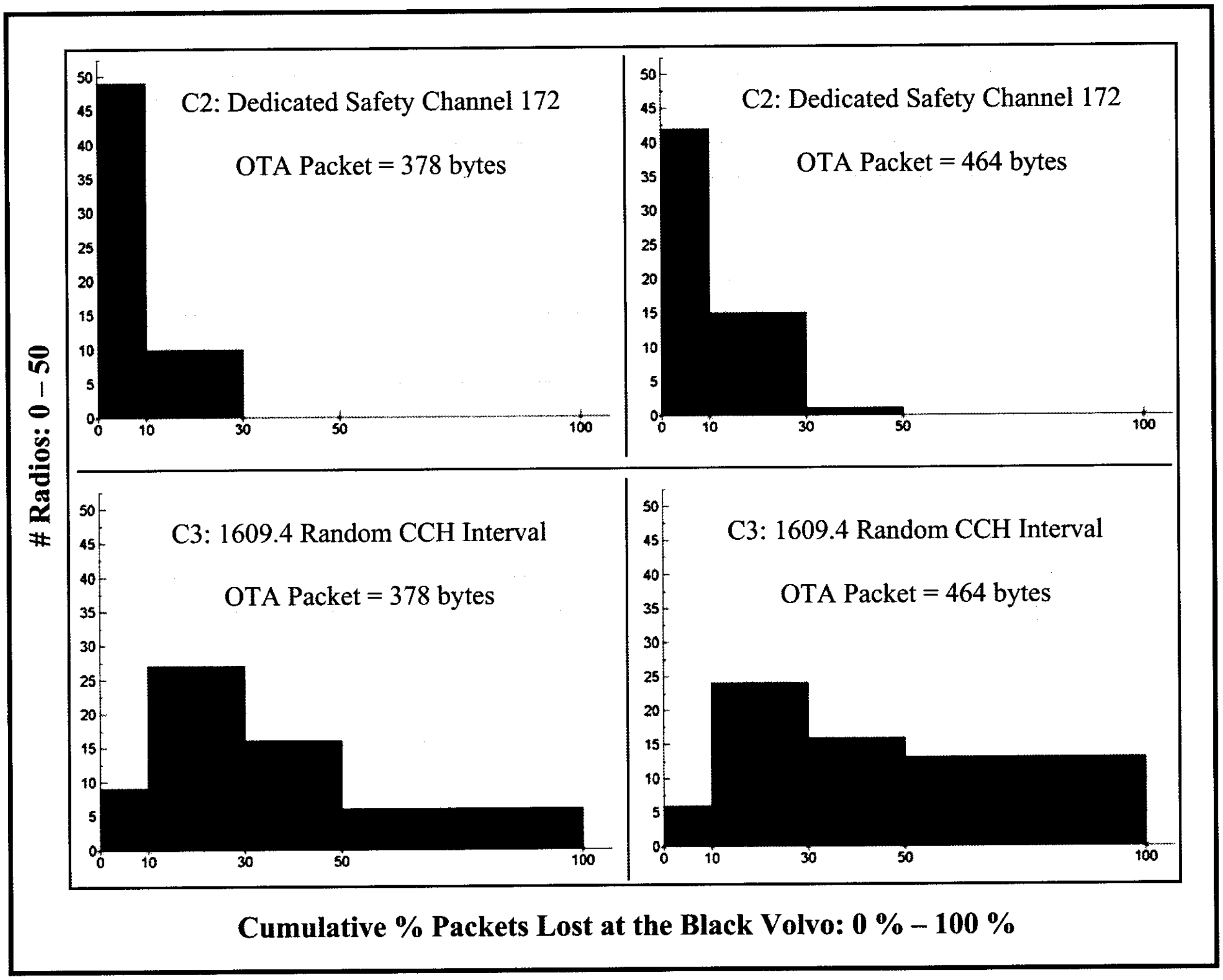


Figure 5: PER vs. OTA Packet Length – Ch. Cfg. 2 & 3 – 60 Tx Radios

3.2 PER vs. Message Transmit Rate

For this test, a 5 Hz message transmit rate was used as opposed to the 10 Hz rate used in the baseline test. Decreasing the transmit rate from 10Hz to 5Hz decreased the PER for both configurations (Figure 6). This was expected and is caused from a lower congestion level when RVs are transmitting less frequently.

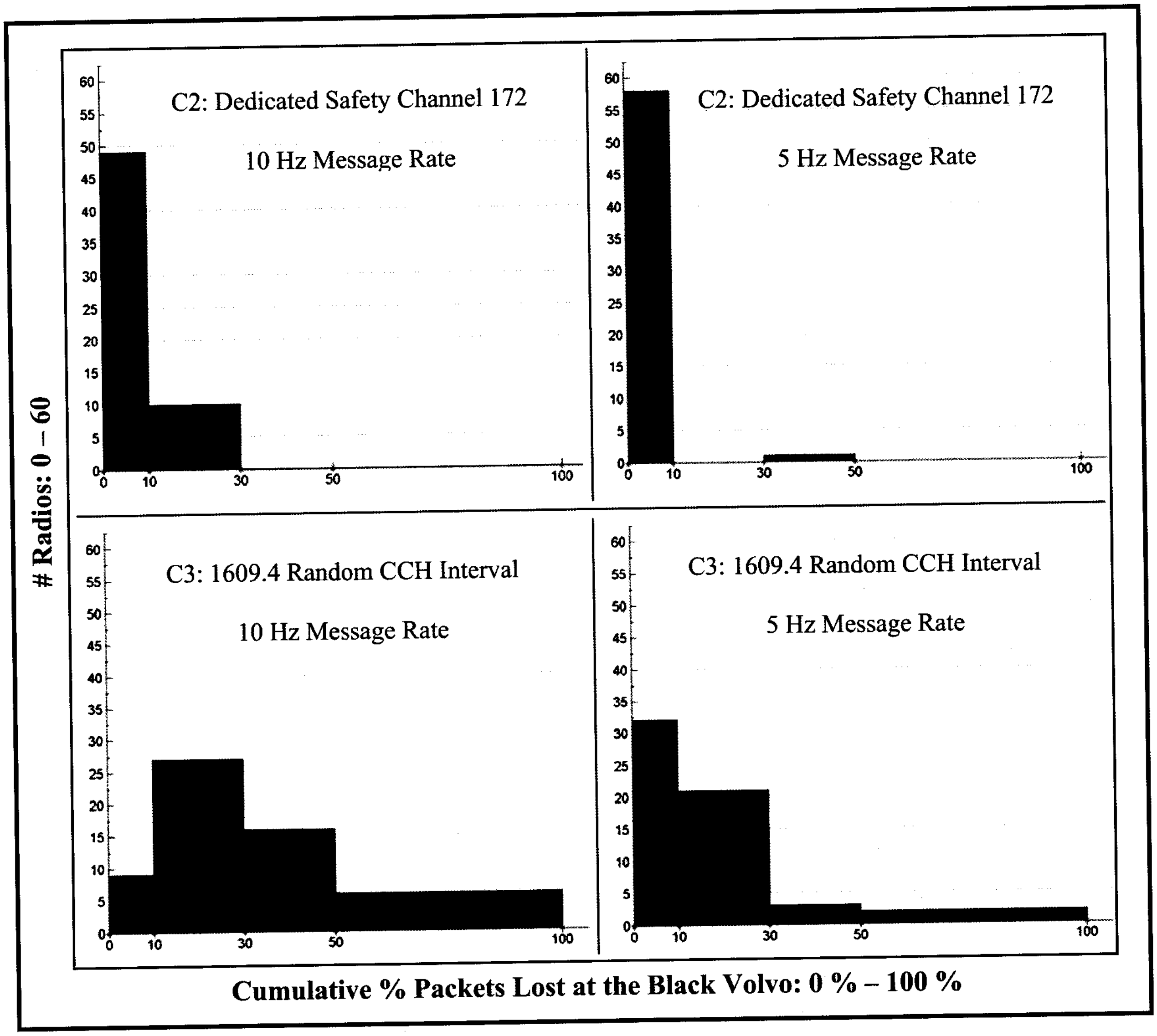


Figure 6: PER vs. Message Transmit Rate – Ch. Cfg. 2 & 3 – 60 Tx Radios

3.3 PER vs. Data Transmit Rate

For this test, a 12 Mbps data rate was used as opposed to the 6 Mbps rate used in the baseline test. Two sets of data are presented below. The first data set is for the black Volvo (V2) which was part of the center cluster of pods and vehicles and in communication range with all of the other radios. The second data set is for the dark blue Cadillac (V3) which was positioned at the far edge of the radio communication and was not in communication range with all of the other radios.

For the black Volvo, which was in the center of radio communication, increasing the data transmit rate from 6 Mbps to 12 Mbps decreased the overall PER for both configurations but appears to have had a larger affect on transmit configuration C3 (Figure 7) perhaps because the results for C2 were already quite good and there was not a lot of room for improvement.

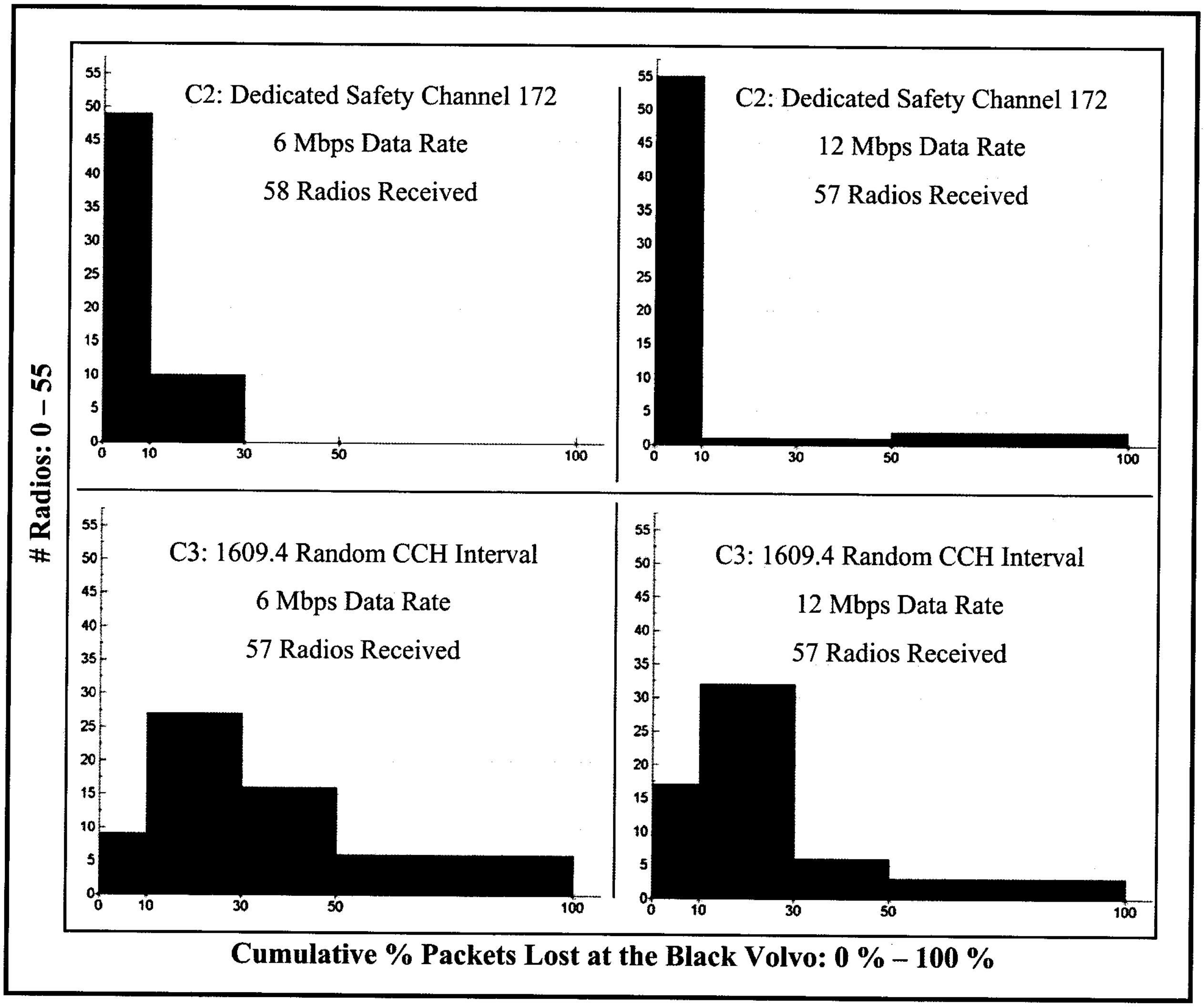


Figure 7: PER vs. Data Transmit Rate at the Center of Radio Coverage – Ch. Cfg. 2 & 3 – 60 Tx Radios

For the dark blue Cadillac, which was on one of the far edges of radio communication, increasing the data transmit rate from 6 Mbps to 12 Mbps increased the overall PER for both configurations, but less so for transmit configuration C3. It also reduced the number of RVs it could communicate with by about ten (Figure 9).

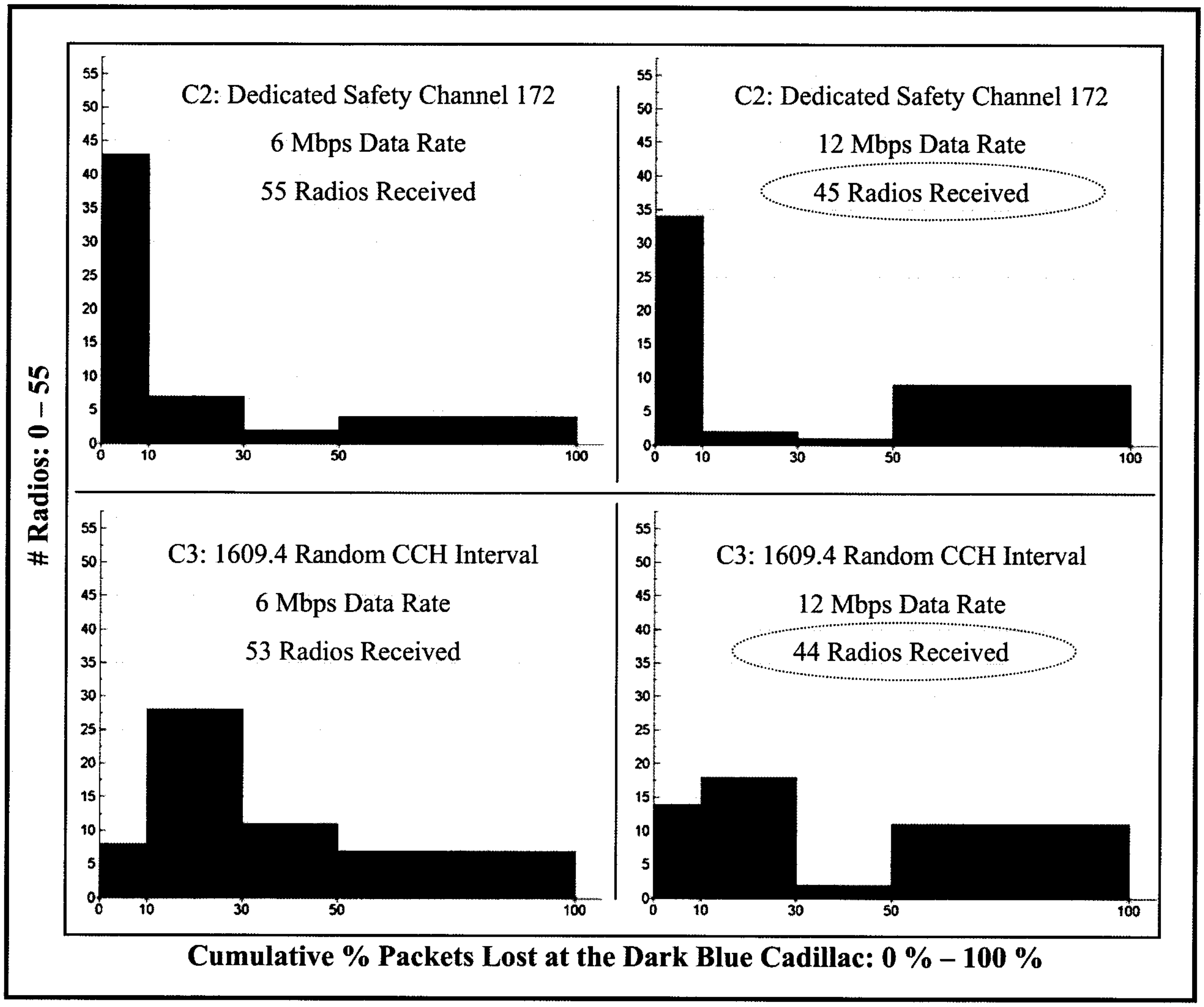


Figure 8: PER vs. Data Transmit Rate at the Edge of Radio Coverage – Ch. Cfg. 2 & 3 – 60 Tx Radios

3.4 PER vs. Data Transmit Rate vs. Range

The following charts show the PER versus range for a 6 Mbps data rate and a 12 Mbps data rate for radios with the same transmit power. Figure 9 shows that increasing the data rate appears to negatively affect some percentage of RVs PER beyond 100m, although low PER is still observed in many RVs up to 300m. As previously noted, transmitting at 12 Mbps appears to have had a more positive affect on transmit configuration C3 than C2. Note that in the Figure 9 range plots, as was the case with the PER versus range results in Section 2.2, the results of the second radio of each OBE unit are excluded due to it having a lower transmit power than the first radio of the OBE.

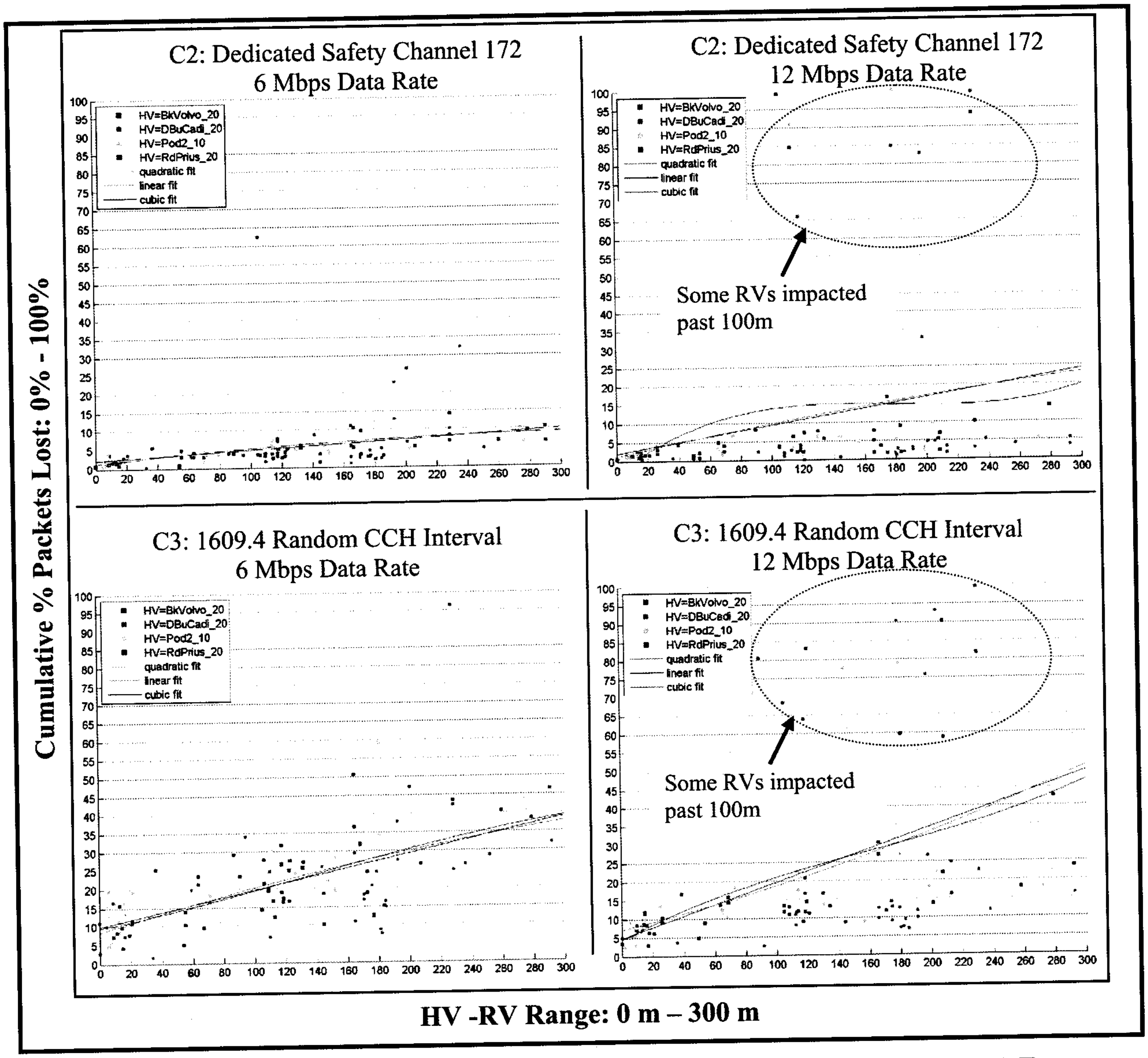


Figure 9: PER vs. Data Transmit Rate vs. Range – Ch. Cfg. 2 & 3 – 60 Tx Radios

3.5 PER vs. Data Transmit Rate vs. RSS

Finally, Figure 10 below shows the PER versus average RSS results presented as a scatter plot for both data transmit rates. Increasing the transmit data rate from 6 Mbps to 12 Mbps decreased the PER for RVs with equivalent stronger signals but reduced the ability to communicate with RVs with weaker signals. At 6 Mbps, packets were received at approximately a minimum -94 dBm, but at 12 Mbps, they were only received at approximately a minimum -90 dBm.

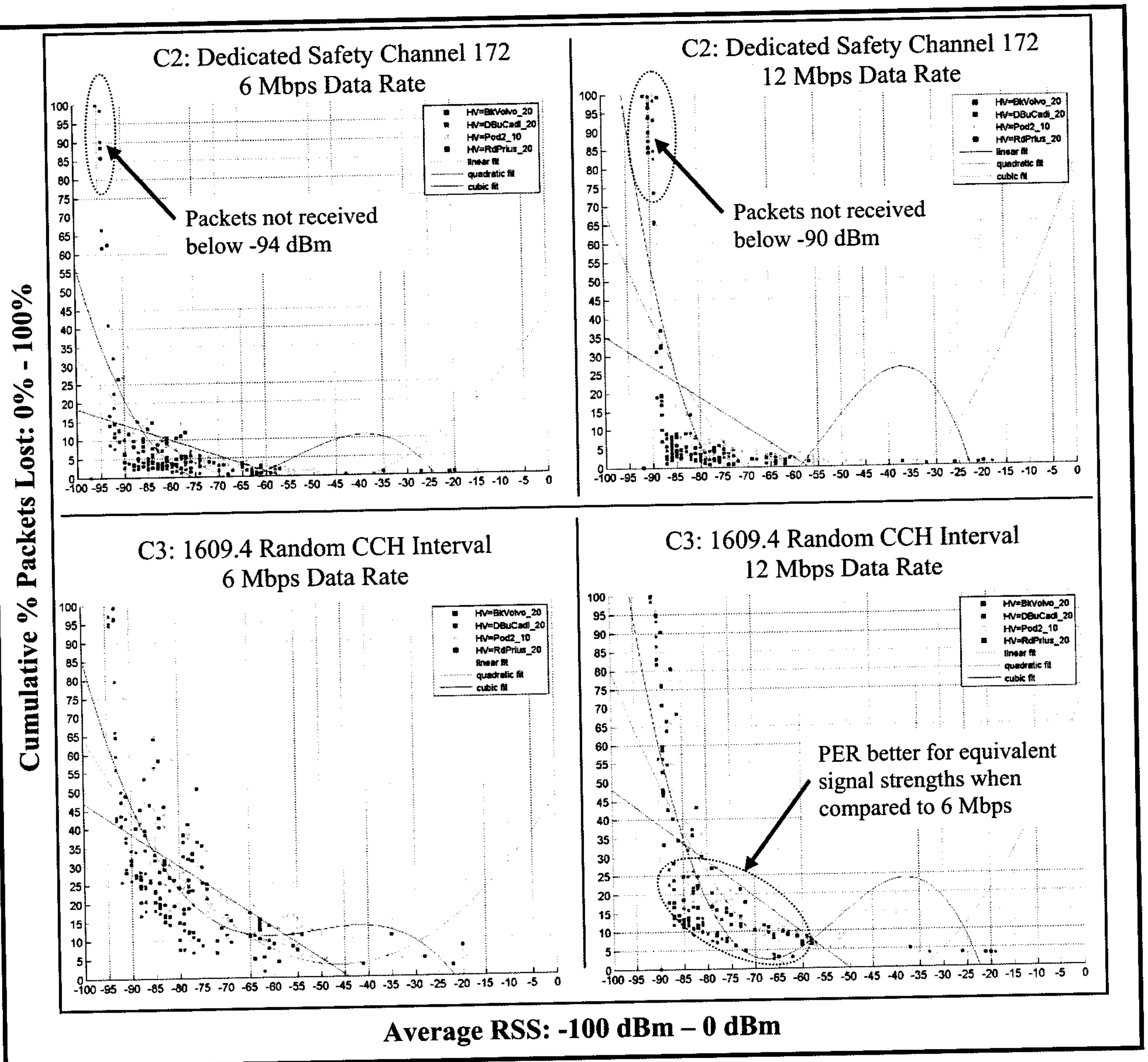
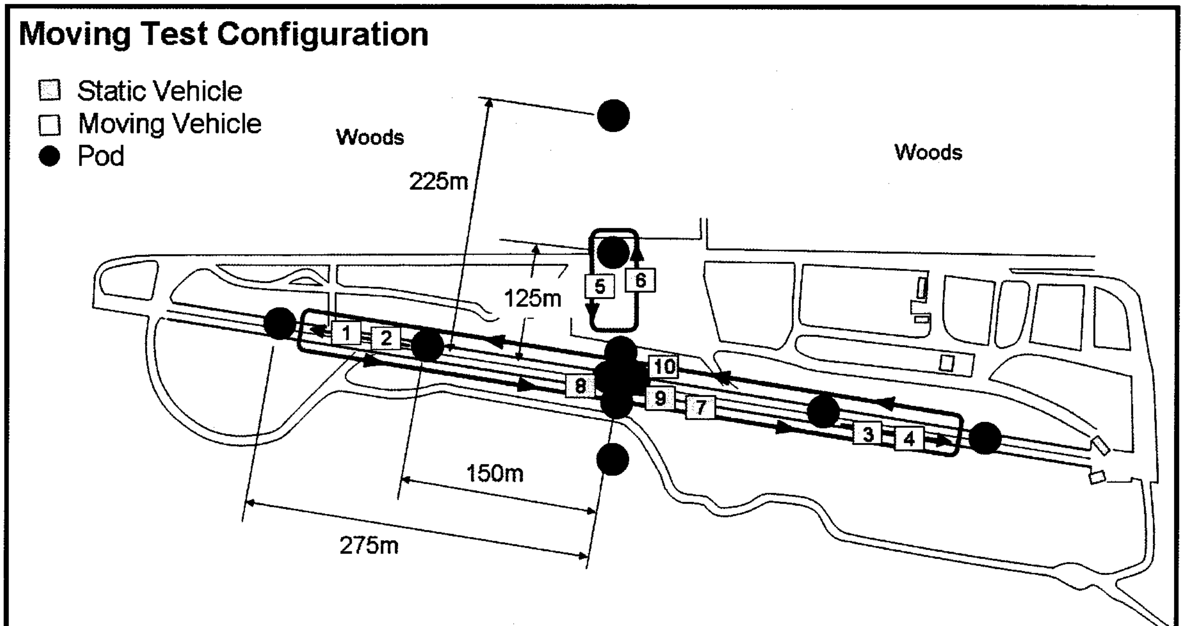


Figure 10: PER vs. Data Transmit Rate vs. RSS – Ch. Cfg. 2 & 3 – 60 Tx Radios

4 Moving Scalability Test Results

In addition to the static deployment tests, a number of moving tests were run to analyze the effects of PER versus distance in a moving environment. For consistency, the pod / vehicle layout for the pods and vehicles that remained static did not change considerably from the all-static tests. It consisted of a center cluster of four pods and four vehicles with the remaining pods placed at varying distances up to 275m from the center cluster. Unlike the static tests all vehicles outside of the center cluster were moving for these tests. Figure 11 provides a diagram identifying the location of each of the pods and vehicles that were used in the tests and identifies which vehicles were static and which were moving.



V1: Blue Acura	V2: Black Volvo	V3: Dk. Blue Cadillac	V4: Gold Acura	V5: Lt. Blue Cadillac
V6: Red Prius	V7: Ford Navigator	V8: Ford Flex	V9: Green Prius	V10: Grey Volvo

Figure 11: Vehicle and Pod Moving Deployment Configuration

Vehicles V2 (HV) and V1 (RV) traveled together with V2 following relatively close behind V1. Similarly vehicles V3 (HV) and V4 (RV) traveled together with V3 following relatively close behind V4. All four vehicles traveled in a big loop thru main track. Vehicles V6 (HV) and V5 (RV) made a smaller loop outside of the track with each one attempting to remain at opposite ends of the loop.

Channel configurations C2 and C3 were tested for three radio scaling increments consisting of 24, 48, and 60 radios. Other than having moving vehicles, the test configuration was the same as the baseline test configuration. Logs were captured on moving vehicles V2, V3, V6, and stationary Pod2 which were considered to be the HVs for these tests.

The data analysis for these tests primarily looked at the PER versus distance from both an increasing range to the RV(s) and a decreasing range to the RV(s) from the HV's perspective. This included looking at the PER among all of the other radios (RVs) in the test in addition to the PER with the principle other moving vehicle (RV) in the test (i.e., V1 for V2, V4 for V3, and V5 for V6). Only the data from the 60 radio scaling increment will be presented.

The following data analysis sections start with a comparison between channel configurations C2 and C3 to show that, similar to the static tests, C2 performs better than C3 from a PER analysis perspective. The remaining data analysis sections only provide the data for channel configuration C2. Since the data is similar for V2 and V3, which were both traveling in a big loop through the main track, only the data from V2 will be presented in order to allow for a comparison between the static and moving test results. This section ends with a PER comparison between the static and moving results and some conclusions drawn from the results of the moving tests.

4.1 Interpreting the Charts

Figure 12 shows the charts that were developed to analyze the PER versus range from the HV perspective for all of the RVs the HV was in communication with. Additional charts are also presented in the analysis sections that show the PER versus range from the HV perspective for the principle RV that the HV was traveling with. To aid in the plotting of the data, the ranges were grouped into 3m bins. Two types of charts were developed:

1. A chart to plot the number of packets received at each range grouping
2. A chart to plot the percentage of packets lost or PER for each range grouping

Each of these charts has multiple plots:

- Blue lines / dots show the # packets / PER for all of the RVs
- Red lines / arrows show the # packets / PER when the HV to RV distance was decreasing
- Green lines / dots show the # packets / PER when the HV to RV distance was increasing or unchanged

For the PER charts linear (solid line) and quadratic fit (dashed line) curves are provided based on the plotted points.

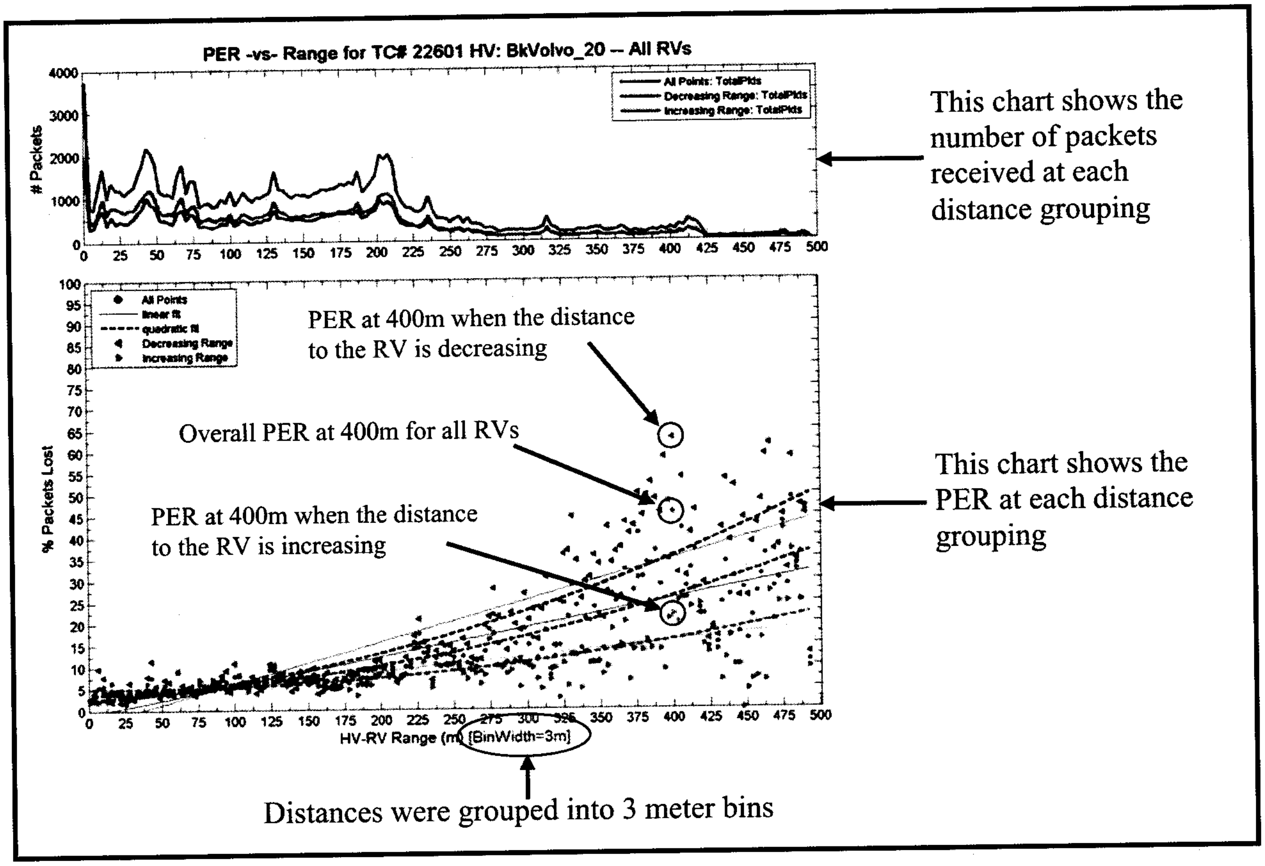
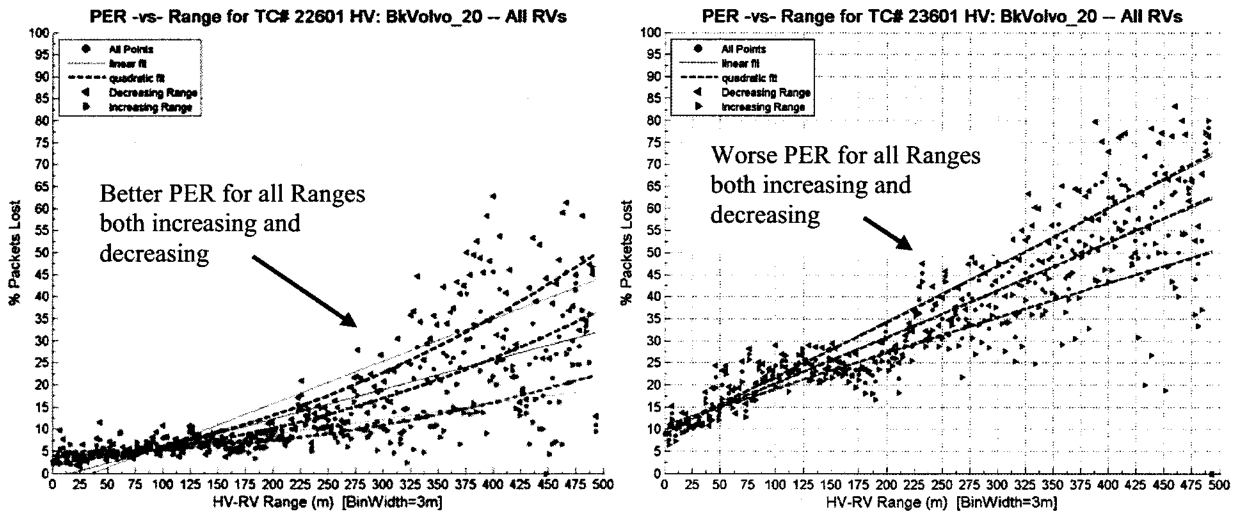


Figure 12: PER vs. Range for Moving Vehicles – Example Plot for 60 Tx Radios

4.2 PER Comparison for Channel Configuration C2 vs. C3

Figure 13 shows a comparison of the results between channel configuration C2 and channel configuration C3 from the perspective of V2 (black Volvo). Similar to the stationary tests, C2 has better PER versus range performance than C3. The results from the perspective of V3 (dark blue Cadillac) are similar and thus not presented. The remaining data analysis sections will go into more details on what the charts show.



C2: Dedicated Safety Channel 172

C3: 1609.4 – Random CCH Interval

Figure 13: PER vs. Range for Moving Vehicles – C2 vs. C3 – 60 Tx Radios

4.3 Cumulative PER for Moving HV with Moving Blocking RV

Figure 14 shows the PER versus range for a moving HV (V2 black Volvo) with a moving blocking RV (V1 blue Acura) for all of the RVs the HV was in communication with. The top chart shows that packets were received from other vehicles at all distances from 0-500m, but most vehicles were within 250m due to the test layout and driving patterns (Figure 11). The bottom chart shows that the PER from RVs located in front of the HV (decreasing range) is worse than from RVs located behind (increasing range). This difference is more noticeable at greater distances. This may be caused from the RV being located in front of the HV, reducing the ability for the HV to receive messages from the forward direction.

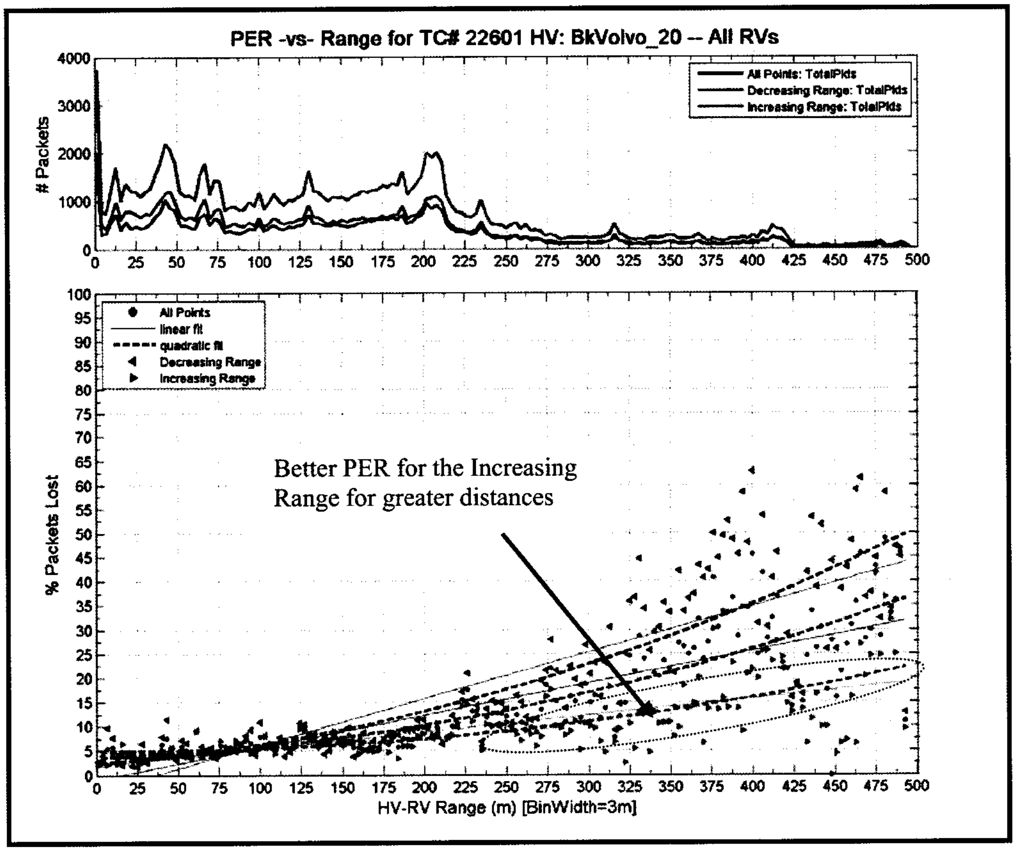


Figure 14: PER vs. Range for Multiple RVs – Moving HV w/ Blocking RV – Ch. Cfg. 2 – 60 Tx Radios

Figure 15 shows the PER versus range from the HV perspective for the principle moving RV that the HV was traveling behind. The top chart shows the distance between the HV and RV ranged between 10m to 60m while the bottom chart shows that the PER from the leading RV to the following HV was less than 10% for most of the distances measured. The congestion level of 60 transmitting radios did not appear to affect the PER of the RV at these relatively close distances.

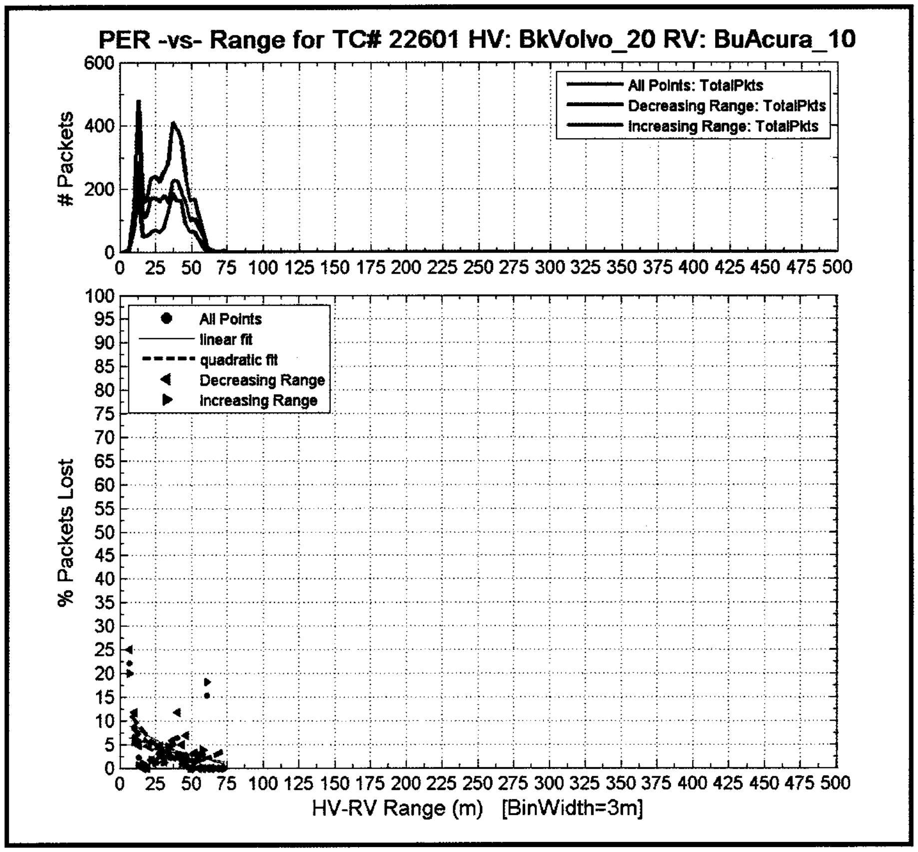


Figure 15: PER vs. Range for Principle RV – Moving HV w/ Blocking RV – Ch. Cfg. 2 – 60 Tx Radios

4.4 Cumulative PER for Moving HV w/ Moving Semi-Blocking RV

Figure 16 shows the PER versus range for a moving HV (V6 red Prius) with a moving semi-blocking RV (V5 light blue Cadillac) for all of the RVs the HV was in communication with. The top chart shows that packets were received from other vehicles at all distances from 0-325m. However, most vehicles were within 225m due to the test layout and driving patterns (Figure 11). The bottom chart shows that the PER from RVs located in front (decreasing range) and behind (increasing range) the HV appears similar. Unlike the previous test, due to the HV and RV driving at opposite ends of the loop in this test, the RV did not continuously block the HV. This may account for the loose grouping of points between 175m and 300m for both the increasing and decreasing range. The slightly better PER observed at the 275-325m range is caused from communication with Pods 8 and 9 which were generally line of sight.

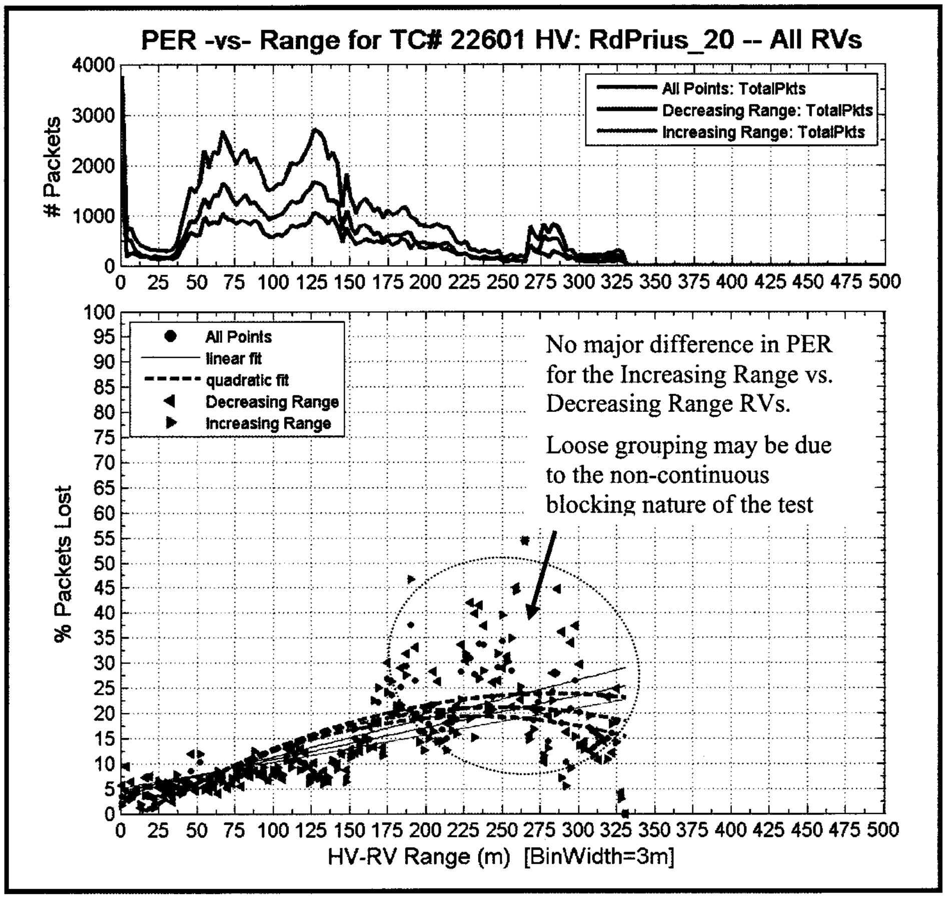


Figure 16: PER vs. Range for Multiple RVs – Moving HV w/ Semi-Blocking RV – Ch. Cfg. 2 – 60 Tx Radios

Figure 17 shows the PER versus range from the HV perspective for the principle moving RV that the HV was traveling with. The top chart shows the distance between the HV and RV ranged between 5m to 100m while. The bottom chart shows the PER of the RV, measured at the HV, was better from the forward direction than the rear. Since the vehicles were relatively close and there were not any obstructions between the two vehicles, the difference in PER may have been caused by antenna placement or vehicle roof curvature.

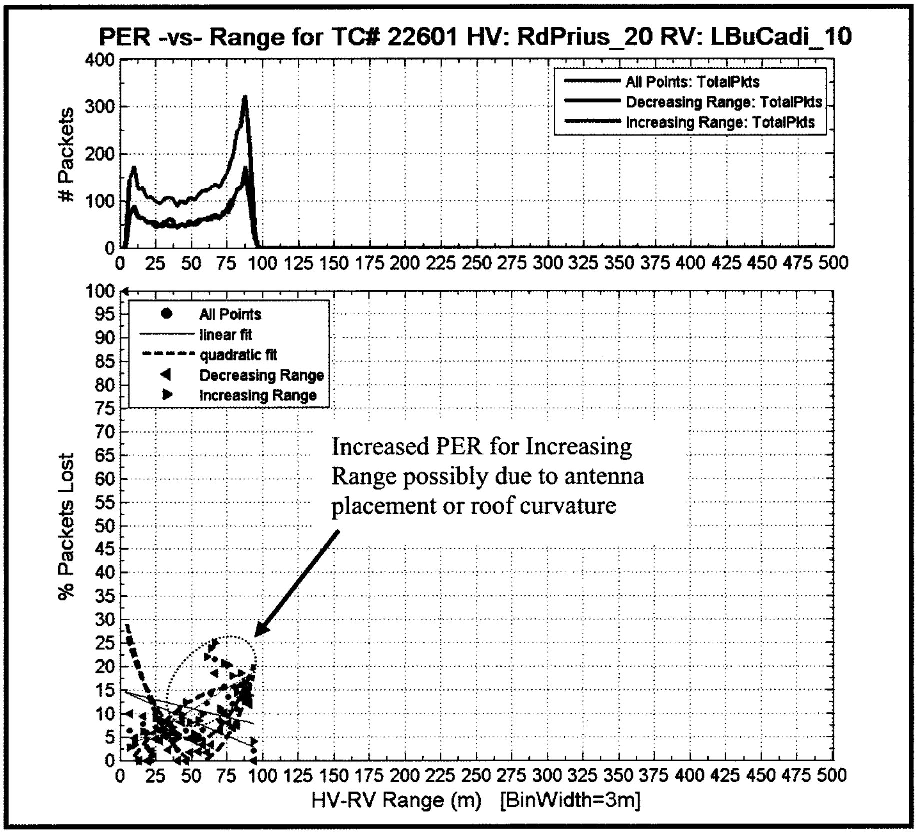


Figure 17: PER vs. Range for Principle RV – Moving HV w/ Semi-Blocking RV – Ch. Cfg. 2 – 60 Tx Radios

4.5 Cumulative PER for Stationary HV

Figure 18 shows the PER versus range for a stationary HV (pod 2) for all of the RVs the HV was in communication with. The top chart shows that most packets received by the HV were at specific distances. Since the HV was stationary these correspond to the stationary RVs (pods and vehicles) in the test. The packets from the moving RVs were received at distances from 0-225m with the furthest stationary pod being at 275m. Recall that packets received from an RV where there is no change in the distance are categorized as "Increasing Range," thus, the green spikes for each of RVs that are stationary with respect to the HV. The bottom chart shows that the PER from all RVs moving towards or away from the stationary HV appears similar. Additional PER results (not shown) between pod 2 and specific RVs also do not show any clear difference in either direction.

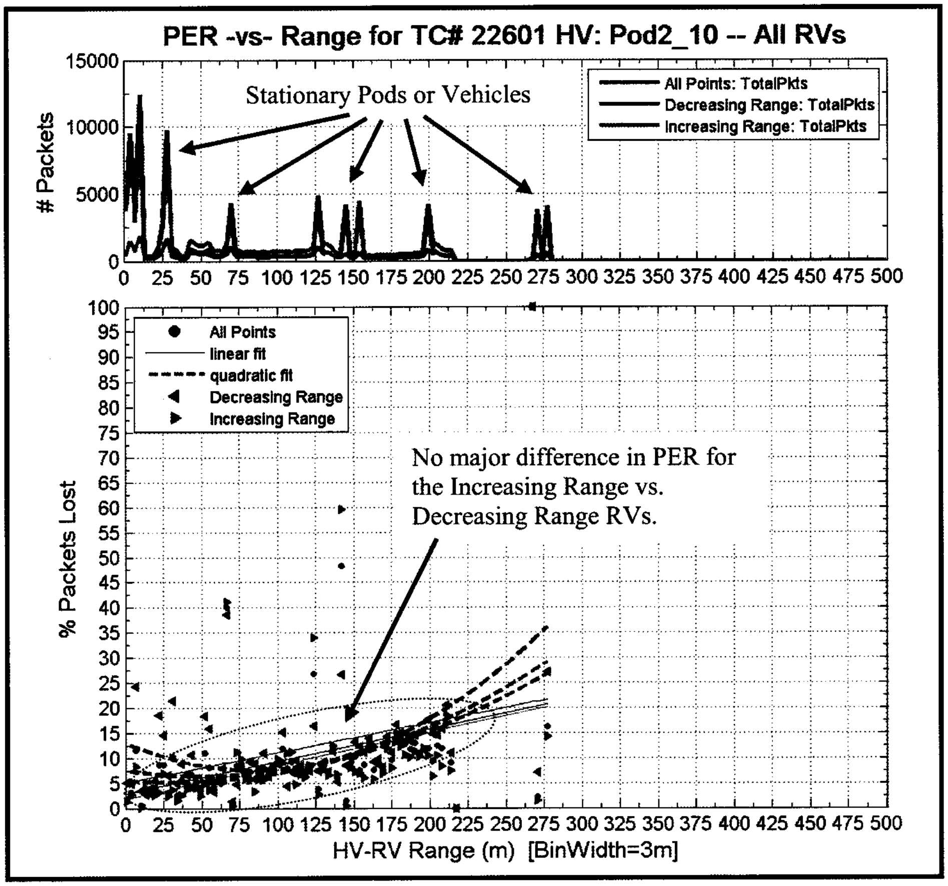


Figure 18: PER vs. Range for Multiple RVs – Stationary HV – Ch. Cfg. 2 – 60 Tx Radios

4.6 PER Comparison for Stationary vs. Moving Vehicle Tests

Figure 19 below shows a comparison of the PER versus range for the stationary test compared to the moving tests. While the stationary tests have less coverage across all possible ranges, the stationary PER results show somewhat better performance than the moving results. The increasing range moving results, with a moving HV and blocking moving RV, have similar performance to the static test results for corresponding ranges out to approximately 300m which was the maximum tested range for the all-static configuration. The increasing range moving results with a moving HV and semi-blocking RV are somewhat worse when compared to the static test which may be caused by the RV periodically blocking the HV.

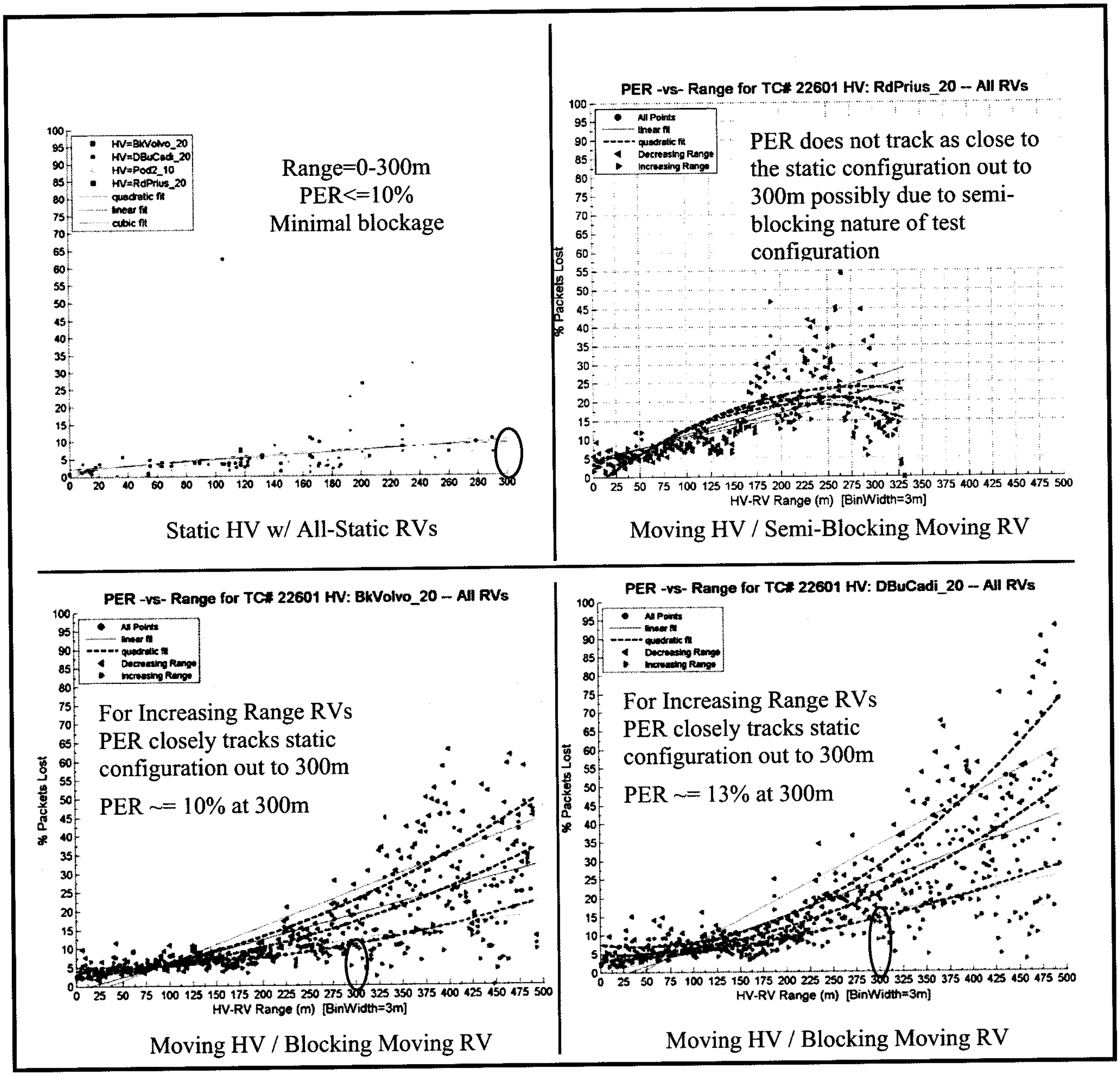


Figure 19: Stationary vs. Moving Vehicle Test Comparison – Ch. Cfg. 2 – 60 Tx Radios

4.7 Moving Test Results Summary and Next Steps

In general the following summarizes the conclusions that can be drawn from the preliminary moving scalability test results:

1. Like the stationary test results, the dedicated safety channel configuration (C2) results in superior performance, when considering PER, compared to using the CCH interval (C3) for transmitting periodic safety messages.

2. The moving test results show a greater range of best case and worse case PER. While not conclusive, the difference in PER appears to be caused from blockage from other vehicles, both moving and stationary.
3. The PER between adjacent moving vehicles (less than 60m apart) was less than 10% with 60 RVs when using the dedicated safety channel (C2). Antenna placement on some vehicles may have also affected the PER.
4. The stationary PER test results were overall better than the moving test results, but the "better case" moving PER test results (i.e., presumed without blockage) were similar to the stationary results.

The results in this appendix are a good start for beginning to understand the effects that combinations of moving and static vehicles may have on PER at a particular HV. More analysis needs to be done on the affect a blocking vehicle may have on the PER at a particular HV as well as combinations of blocking vehicles (e.g., multiple vehicles blocking the HV, vehicle blocking the RV, etc.).

As was mentioned in the main body of the final report, some of the next steps include incorporating lessons learned into future projects where Vehicle-to-Vehicle (V2V) system scalability has to be proven beyond the achievable total number of units within this project (i.e., 60). This includes lessons learned in test bed design and development, SW design and stability, and scalability testing logistics.

Appendix XXIX. USDOT, *V2V Interoperability Project*, USDOT ITS Connected Vehicle Workshop (Sept. 25, 2012).

UNITED STATES
DEPARTMENT OF TRANSPORTATION

V2V INTEROPERABILITY PROJECT

USDOT ITS Connected Vehicle Workshop

Mike Lukuc, NHTSA Research

September 25, 2012

V2V Safety Framework

Maturing the V2V Research	Model Deployment	Evaluation	Supporting Policy Elements	Moving Towards a Decision
Initial Crash Problems	Benefits Framework	Evaluation Plan	Implementation	Safety Benefits
Performance Measures	Driver Clinics	Data	Technical	Performance Requirements
Testing Procedures	Performance Testing	Conduct Evaluation	Legal	Test Procedures
Interoperability Requirements	Model Deployment	Run Simulations		Driver Acceptance
Initial Security Models	Experimental Design			
Driver Vehicle Interface Guidance				

- Moving Towards an Operation Model
- Data Collection
- Data Evaluation & Analysis
- Establishing an Operational Environment
- Results

Overview

What is V2V Interoperability?

- The ability for V2V safety systems to successfully function across any, and all, equipped vehicles regardless of make/model or model year

V2V-Interoperability Project:

- Follow-on project to CAMP-VSC 2 / US DOT VSC-A project (2006-2009)
- Project Duration:
  - Phase I: 30 month project - January 2010 - June 2012
  - Phase II: 21 month extension through March 2014
- Collaborative effort between 8 Automotive OEMs and US DOT

CAMP
Vehicle Safety Communications 3

Mercedes-Benz, GM, TOYOTA, HONDA (Honda R&D Americas), Ford, NISSAN, HYUNDAI-KIA MOTORS, VOLKSWAGEN

Intelligent Transportation Systems

NHTSA www.nhtsa.gov

RITA

Project Objectives

- Address 5.9 GHz DSRC technical issues related to interoperability, scalability, security, and data integrity / reliability
- Provide necessary inputs into the relevant standards development and related efforts, as required, in order to ensure a deployable standards-based system

V2V Safety Communications Interoperability

- Task Goal
  - To achieve V2V safety communications and security interoperability between On Board Equipment (OBE) systems from different manufacturers
- Accomplishments
  - Specified preliminary minimum device requirements for V2V safety communications and security
  - Worked with 4 suppliers to develop On-Board Equipment (OBEs) to meet requirements
  - Conducted interoperability testing and analyzed interoperability test results
  - Developed and implemented remediation recommendations for device requirements and industry standards
  - Achieved device level Vehicle-to-Vehicle (V2V) safety communications and security interoperability between OBEs from different manufacturers

V2V Safety Communications Scalability

- Task Goal
  - Identify a transmission control protocol for scalable V2V safety communications that will preserve the performance of V2V safety applications in both congested as well as un-congested communication environments.
- Primary Transmit Test Configurations to Address the Goal
  - Baseline 1 – 10 Hz fixed BSM transmit rate
  - Baseline 2 – 5 Hz fixed BSM transmit rate
  - Algorithm X – Adaptive control of the BSM transmission rate and transmission power based on a host vehicle position tracking error estimation and channel utilization assessment
  - Algorithm Y – Adaptive control of the BSM transmission rate based on reported channel utilization assessments from neighboring vehicles and that measured by the host vehicle

V2V Safety Communications Scalability

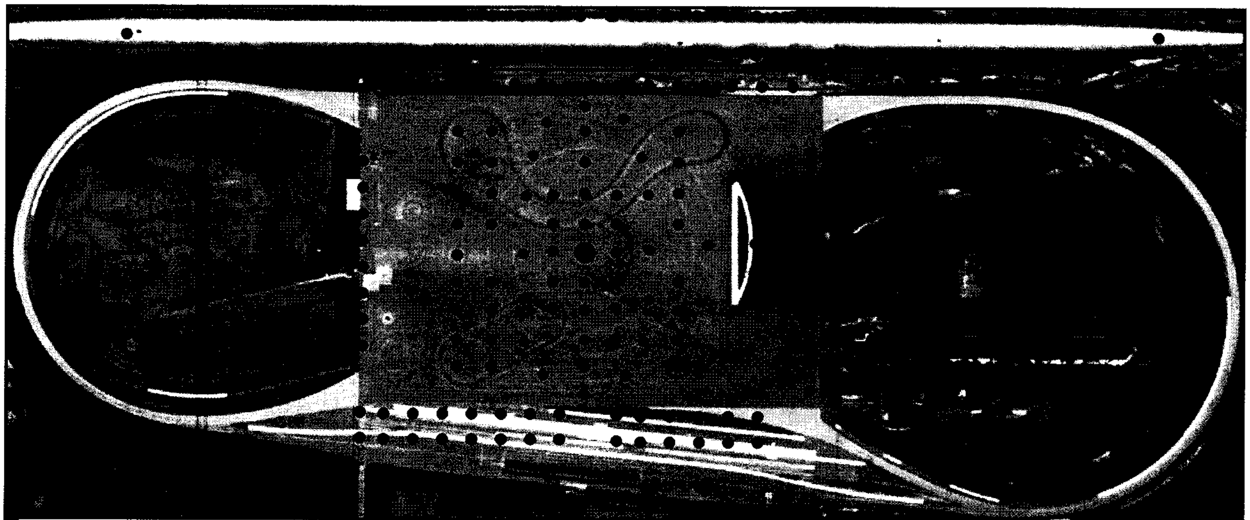
- Metrics for analyzing transmit test configuration performance
  - Packet Error Rate (PER): Ratio of the number of missed packets at a receiver from a particular transmitter and total number of packets sent by that transmitter
  - Inter Packet Gap (IPG): Time between successive successful packet receptions from a particular transmitter
  - Position Tracking Error (TE): Difference between a transmitter's position and a receiver's estimate of the transmitter's position
  - Channel Busy Percentage (CBP): Ratio of the time during which the wireless channel is busy (energy level is higher than carrier sensing threshold) to the period of time over which CBP is being measured
  - Vehicle Safety Application Range Error: Threat range error in actual warning range versus the nominal warning range assuming fixed speed and acceleration

V2V Safety Communications Scalability

- Testing Increments and Locations
  - 50 Vehicle Test
    - Transportation Research Center (TRC) from November 11 - 18, 2011
  - 100 Vehicle Test
    - Naval Air Station Alameda from January 24 - 31, 2012
  - 200 Vehicle Test
    - TRC from March 24 – April 3, 2012
- 200 Vehicle Test
  - 6 primary driving configurations encompassing 8 driving scenarios
    - Highway – 2 Scenarios
    - Intersection – 1 Scenario
    - V2V Safety Application – 1 Scalability Scenario w/ 3 Safety Application Scenarios
    - High Dynamics Winding Road – 1 Scenario
    - Hidden Node – 2 Scenarios
    - Sudden Loading Effect – 1 Scenario
  - 3 OBE scaling increments: 100, 150, & 200 OBEs

Scalability Testing

As an animation…



NOTE: The animation in this diagram is for illustration purposes only. The actual deployment of static and moving vehicles will be determined through the activities of this task.

SCALABILITY TESTING

…and in reality